Riverbend Example for EGDe$

1 Riverbend Case Study Overview

This example contains all information required for the "Riverbend Example" and the "Riverbend Example with Uncertainty". If you are only interested in the example without uncertainty you may ignore any distributions or distribution related variables. For simplicity, the tables of inputs and outputs for the "with Uncertainty" example are separate from those for the example without uncertainty. This is a highly simplified example only meant for illustrative purposes and is not a true representation of a full economic or LCC analysis. Furthermore, many of the assumptions made herein are unjustified and should not be considered as recommendations.

Riverbend, a small city of 50 000 people located in a valley along Central River, was originally settled 160 years ago by farmers and loggers. The city is comprised mainly of middle-class families with a median income close to the national average. Over that time period, the city has maintained much of its agricultural heritage while simultaneously cultivating robust manufacturing, finance, and real estate sectors in its economy. Recently, the logging and mining sectors have started to decline. Riverbend has managed to avoid major economic issues by attracting employers to other sectors.

The city maintains an important relationship with the neighboring city of Fallsborough, which is located on the other side of Central River. The two cities are linked by a four-lane interstate bridge that is vital to Riverbend logistically. The bridge represents the only route for traffic into the city. It routinely fails to meet the traffic demand during peak hours and is sensitive to earthquake events.

The Riverbend collaborative planning team (CPT) considered two alternatives to increase community resilience against seismic event hazards. Consideration of seismic events was driven by the known hazards in the region and the potential loss of life, infrastructure damage, and economic impacts if a disaster occurs. In developing their alternative resilience plans, the CPT assumed a 3 % real discount rate and a 50-year planning horizon. The design event was an earthquake with a 25-year return period. All discounting is performed using continuous compounding.

Plan 1. Upgrade the Central River Bridge (*Retrofit*)

The existing bridge is scheduled and budgeted for a deck replacement in 10 years, creating an opportunity to upgrade the bridge to be more resilient to seismic events. To upgrade the bridge, it must be closed to emergency services and regular traffic. The additional vehicle-hours from rerouting, as well as the effect on emergency vehicles, are real costs that must be considered. Heavier traffic on alternative routes will also decrease the life of those roads, as they may not be designed for the additional equivalent single axle loads (ESALs) they would be carrying.

Plan 2. Construct a Second Bridge Over the Central River (*New Bridge*)

The new bridge would be built with an offset alignment from the original bridge and according to current seismic codes and a design life of 125 years. The original bridge would continue to service traffic, but should a seismic event occur, all traffic will be maintained by the new bridge. Sharing traffic between the bridges will reduce traffic during peak hours that would benefit long-term economic development. Apart from the immediate benefits, the new bridge would be used to carry traffic when the old bridge eventually needs to be replaced and would also support a non-motorized path.

2 Assumptions

The following values are assumed for both alternatives:

Planning horizon: 50 years
Recurrence rate of Seismic Event: 25 years
Real discount rate: 3 %
Value of a statistical life: 7 500 000 USD

Other key assumptions have been made to simplify the example. These are not necessarily realistic and should not be considered prescriptive for an actual LCC analysis.

1. There is no dependence between distributions, for instance for distributions of cost and distributions of indirect cost. EDGe$ currently does not implement such considerations, although for some distributions such dependencies would exist.
2. There is no uncertainty related to the return rate of the disaster.
3. Construction is assumed to occur entirely in year zero.
4. Construction externalities are negligible due to their assumed short time frame.
5. The analysis compares all values relative to the implicit option of doing nothing.

Assumptions related to specific values derived for the analysis are mentioned as they arise from the narrative.

3 Data

3.1 Cost Data

Retrofit

Estimates place the direct cost (including engineering) of retrofitting the bridge at 3 000 000 USD[1], with an additional 500 000 USD in indirect costs (including costs of diverted traffic) based on Bhatt and Martinez (2013). Concerned about the realities of financing a project of this size, uncertainty estimates were also obtained. Based on typical values from literature, the planners estimate the upper end of the costs due to cost overrun to be 128 % the point estimates (Flyvbjerg 2004). Although the planning team assumes the project being under-budget is highly unlikely, there is a chance a bid may come in under their estimate should they choose to retrofit and be on budget. The lower end is assumed to be 95 % of the point estimates. Triangular distributions were assigned accordingly. Additional operations, maintenance, and repair (OMR) costs are negligible.

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[1] Based on estimate for bridge replacement for I-94 from Masonic Blvd. to M-29

New Bridge

The planning team divided the costs related to constructing a new bridge into two categories. The cost associated with constructing the bridge, and those associated with constructing new road and upgrading the existing road on either side of the river to accommodate the new bridge. The direct costs of constructing the new bridge are estimated at 4 250 000 USD [2]. This includes purchasing right-of-way, land acquisition, and environmental impact study, and engineering. Indirect costs are 175 000 USD based on values from Bhatt and Martines (2013), and include the indirect rate for the construction firm, as well as the costs of an environmental study. The new bridge would also add 25 000 USD a year in OMR costs. Triangular distributions are assumed for direct and indirect costs under the 95 % to 128 % range used for the retrofit costs. OMR uses a rectangular distribution bounded by 21 375 USD and 30 000 USD.

The additional road work is estimated to cost 2 500 000 USD in direct costs based on Florida Dept. of Transportation numbers[3], 150 000 USD[4] in indirect costs, and add a yearly OMR cost of 3710 USD (U.S. Forest Service 2011). Triangular distributions are assumed for direct and indirect costs under the 95 % to 128 % range used for the retrofit costs. OMR uses a rectangular distribution bounded by 3500 USD and 4250 USD.

3.2 Benefit Data

Retrofit

Event Related Benefits (*Benefits* screen in EDGe$)

A study[5] examining the benefits of retrofitting the bridge indicated that the retrofit would reduce direct losses by 260 000 USD, indirect losses by 2 000 000 USD, and response and recovery losses by 600 000 USD. A conservative estimate put the coefficient of variation (COV) for each category at roughly 0.3. Gaussian distributions[6] were assumed for all variables. These values represent reductions over the alternative of doing nothing assuming that the instigating disaster would produce identical losses every time.

Fatalities Averted

By retrofitting the bridge, the possibility of a failure of a component, or the inability of an emergency vehicle to respond in a prompt time is reduced. This leads to fewer fatalities per disaster. Rough

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[2] Based on estimate for bridge replacement for I-94 from Masonic Blvd. to M-29

[3] Values estimated using Florida Dept. of Transportation's "Generic Cost Per Mile Models" <http://www.fdot.gov/programmanagement/Estimates/LRE/CostPerMileModels/CPMSummary.shtm>, retrieved in July 2017, and assuming 1.5 miles of new road

[4] Using a 6 % rate based on Florida Office of Inspector General (2013).

[5] The cost of completing this study is assumed already incurred, making it a sunk cost. Therefore, it is not included in the lifecycle cost analysis performed later.

[6] Also referred to as the normal distribution.

estimates put the number of fatalities averted at 0.1 per event.[7] The value of statistical life for both alternatives is 7 500 000 USD.

Non-Disaster Related Benefits (Resilience Dividend)

There are no assumed non-disaster related benefits to the retrofit. The bridge will continue to operate at original capacity after completion.

Externalities

No externalities are considered for the retrofit in this analysis. Realistically, there would be externalities; noise due to construction activity, or increased confidence in the bridge's safety, for instance.

New Bridge

Hazard-Related Benefits (*Benefits* screen in EDGe$)

A study on the earthquake-related loss reductions was commissioned for the new bridge alternative. There are no direct loss reductions, as the old bridge will behave identically to a scenario where no resilience action is taken and any damage it sustains will not affect the new bridge. For estimation purposes, it is assumed that the new bridge will perform as designed under seismic loading and will therefore not increase the amount of direct losses. Indirect loss reductions are estimated to be 3 500 000 USD, due to no interruption to traffic flow across the river while the old bridge is repaired. Response and recovery losses are reduced by 1 000 000 USD due to the ability of emergency vehicles to travel easily across the river. As before these values are assumed to be normally distributed with a COV of 0.3.

Fatalities Averted

Unlike the retrofit alternative, the new bridge avoids fatalities by maintaining traffic flow, even if there is a failure on the old bridge. This allows emergency vehicles to continue to travel as needed across the river. In total, 0.2 fatalities[8] are expected to be averted under the new bridge alternative.

Non-Disaster Related Benefits (Resilience Dividend)

The new bridge helps reduce travel time during peak flow by providing alternative lanes and better roads on either side of the bridge. A study found this would save 100 000 USD per year in vehicle-hours

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[7] Uncertainty around fatalities averted is being considered for a future iteration of EDGeS. Uncertainty output for fatalities averted in the current version of the tool is related to uncertainty in the recurrence rate.

[8] Indicating injuries and no deaths.

lost in traffic[9]. A triangular distribution is assumed for these savings, with a low value of 70 000 USD and a high value of 115 000 USD.

3.3 Externalities

Transportation projects are traditionally associated with negative externalities. New roads bring traffic, which brings noise and pollution to the local area. That is not the case here. It is assumed that traffic stays constant after construction, so no new noise would be associated with the new bridge and by reducing vehicle-hours in traffic, the amount of pollution decreases. Using data from Queensland Australia's government (Department of Transport and Main Roads 2011), and assuming the new bridge saves the following in travel distance:

- The equivalent of 1 car traveling 1000 km in distance a year,
- The equivalent of 1 light freight vehicle carrying 6.8 tonnes 200 km in travel distance a year[10]
- The equivalent of 1 heavy freight vehicle carrying 22.8 tonnes 75 km in travel distance a year,

the annual reduction in externalities due to water pollution can be estimated to be 39 081 USD, and externalities due to greenhouse gasses are 77 329 USD. Additionally, the walking path increases community connectivity, producing another 39 799 USD in positive externalities. This highlights an important step that must be taken if using outside data sources. All relevant values must be converted to a consistent dollar unit, i.e., 2017 U.S. Dollars, to account for inflation and other price changes (specific changes in local labor market and prices as represented by the consumer price index)[11].

Under uncertainty analysis, these externalities are assumed to follow a discrete distribution with three values; low, with a 0.25 probability, most likely (Mode), with a 0.5 probability, and high, with a 0.25 probability. Specifically:

- Greenhouse gases: Low - 64 043 USD, Mode - 77 329 USD, High - 81 387 USD
- Water pollution: Low - 24 587 USD, Mode - 39 081 USD, High - $56 566 USD
- Linking communities: Low - 21 750 USD, Mode - 39 799 USD, High - 53 006 USD

4 EDGe$ inputs

[9] This analysis assumes that traffic volume remains constant and no economic growth occurs in both alternatives. In practice, a more efficient road network would attract more users and more regional or local growth. As before, the cost of the study is assumed as a sunk cost.

[10] The definition of light and heavy freight comes from U.S. Dept. of Transportation (2014). Capacity uses the mid-range from Table 3-8 of U.S. Dept. of Transportation (2014) converted to metric tons.

[11] This was not necessarily done for every value in all case studies. Some values, like the value of a statistical life, are set by governmental agencies and only change when updated, while others were used "as is" to enhance results interpretation. In practice all values that are inflation dependent must be brought to a consistent U.S. dollar year.

This section summarizes the inputs into EDGe$ for each of the two resilience plans being considered by Riverbend, described in detail previously. These values will be of use in reviewing the features of EDGe$ as well as in the Tutorial on the use of the EDGe$.

Analysis Parameters (applicable to both alternatives):

- Planning horizon: 50 years
- Recurrence rate of Seismic Event: 25 years
- Real discount rate: 3 %
- Value of a statistical life: 7 500 000 USD

Point Estimate Analysis

Table 1 summarizes the input into EDGe$ for the *Retrofit* alternative[12], ignoring uncertainty. The input for the *New Bridge* alternative is provided in Table 2[13]. All cost values are assumed to occur at year zero.

Table 1. EDGe$ input for Retrofit option using point estimates

Class	Item	Retrofit
Costs	Direct Costs	$3 000 000
	Indirect Costs	$500 000
On-Disaster Benefits	Direct Loss Reduction	$260 000
	Indirect Loss Reduction	$2 000 000
	Repair and Replacement Loss Reduction	$600 000
Estimated Fatalities Averted[14]		0.1

All costs are assumed at starting at year zero, with all OMR costs being yearly. The resilience dividend is assumed to begin accruing annually in year one, as do all externalities. All externalities are assumed to be owned by the community.

Table 2. EDGe$ input for New Bridge option using point estimates

Class	Item	New Bridge
Costs	Bridge Construction Direct Costs	$4 250 000
	Bridge Construction Indirect Costs	$175 000
	Bridge Construction OMR Costs	$25 000 annually
	Additional Roadwork Direct Costs	$2 500 000
	Additional Roadwork Indirect Costs	$150 000
	Additional Roadwork OMR Costs	$3710 annually
On-Disaster Benefits	Indirect Loss Reduction	$3 500 000
	Repair and Replacement Loss Reduction	$1 000 000
Estimated Fatalities Averted		0.2

[12] For brevity, any potential EDGeS inputs for which there were no values in the alternative are omitted from this and all future tables.
[13] For brevity, all tables in this document with mixed units use *$* before a dollar amount to denote USD
[14] Although this benefit occurs on earthquake occurrence, it is separated from the input for other on-disaster benefits in EDGeS to account for differences in input.

Resilience Dividend	Reduced Commute Time	$100 000 annually
Externalities	Reduced Greenhouse Gas Emissions	$77 329 annually
	Reduced Water Pollution	$39 081 annually
	Better Linking of Communities	$39 799 annually

Analysis under uncertainty

Table 3 summarizes the input into EDGe$ for the *Retrofit* alternative under uncertainty. The input for the *New Bridge* alternative is provided in Table 4. All cost values are assumed to occur at year zero.

Table 3. EDGe$ input for Retrofit option under uncertainty

Class	Item	Distribution Type	Parameters
Costs	Direct Costs	Triangular	Low – $2 850 000 Most Likely – $3 000 000 High – $3 840 000
	Indirect Costs	Triangular	Low – $475 000 Most Likely – $500 000 High – $712 500
On-Disaster Benefits	Direct Loss Reduction	Gaussian	Mean – $260 000 Std. Dev – $78 000
	Indirect Loss Reduction	Gaussian	Mean – $2 000 000 Std. Dev – $600 000
	Repair and Replacement Loss Reduction	Gaussian	Mean – $600 000 Std. Dev – $180 000
Estimated Fatalities Averted		Deterministic	Value – 0.1

All costs are assumed to start in year zero. Additionally, all OMR costs reoccur annually. The resilience dividend is assumed to begin accruing value annually in year one, as do all externalities in this example. All externalities are assumed to be owned by the community planning the resilience project.

Table 4. EDGe$ input for New Bridge option under uncertainty

Class	Item	Retrofit	
Costs	Bridge Construction Direct Costs	Triangular	Low – $4 037 500 Most Likely – $4 250 000 High – $5 440 000
	Bridge Construction Indirect Costs	Triangular	Low – $166 250 Most Likely – $175 000 High – $224 000
	Bridge Construction OMR Costs[b]	Triangular	Low – $21 375 High – $30 000
	Additional Roadwork Direct Costs	Triangular	Low – $2 375 000 Most Likely – $2 500 000 High – $3 000 000
	Additional Roadwork Indirect Costs	Rectangular	Low – $142 500 Most Likely – $150 000 High – $180 000
	Additional Roadwork OMR Costs[b]	Rectangular	Low – $3500 High – $4250
On-Disaster Benefits	Indirect Loss Reduction	Gaussian	Mean – $3 500 000 Std. Dev – $1 050 000
	Repair and Replacement Loss Reduction	Gaussian	Mean – $1 000 000 Std. Dev – $300 000
Estimated Fatalities Averted		Deterministic	Value – 0.2
Resilience Dividend	Reduced Commute Time[b]	Triangular	Low – $70 000 Most Likely – $100 000 High – $115 000
Externalities	Reduced Greenhouse Gas Emissions[b]	Discrete[a]	Low – $64 043 Most Likely – $77 329 High – $81 387
	Reduced Water Pollution[b]	Discrete[a]	Low – $24 587 Most Likely – $39 081 High – $56 566
	Better Linking of Communities[b]	Discrete[a]	Low – $21 750 Most Likely – $39 799 High – $53 006
[a] Low has a 0.25 probability of occurrence, Most Likely has a 0.5 probability of occurrence, High has a 0.25 probability of occurrence [b] Annually Recurring			

5 EDGe$ Output

Inputting the values from Table 1 and Table 2 into EDGe$ according to the previous sections, and running the analysis using point estimates, yields Table 5. Red dollar values in parentheses indicate a negative value for all tables in this section.

There are two *NPV* s given in the output, *with* externalities and *without* (present expected values are given for costs and externalities as well). Based on the *NPV* without externalities the *Retrofit* is preferable over the *New Bridge* as it has a higher *NPV*. In this case both options have a positive *NPV* meaning both represent net savings based on their discounted cash flows, however that may not always be the case. If the project is optional and both *NPV*s are negative, it may be that the best option economically is the implicit third alternative of doing nothing. Whether doing nothing has any political ramifications that may compel action is also a consideration, though not necessarily an economic one.

The inclusion of externalities is not an obvious decision in all cases. Although these externalities represent benefits, they are accrued by parties outside of the decision makers and may never materialize as actual cash flows. Another difficulty is where to cut off external parties[15]. The reduction in pollution could also decrease costs at a water treatment plant downstream for instance. Where the boundaries should be set for externalities needs to be seriously considered if external parties are to be included. The final decision in this case is the same regardless of the inclusion of externalities or which economic indicators are used; the *New Bridge* alternative is the preferred option[16].

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[15] In this context "external" means outside of the parties whose costs are internalized in the analysis.
[16] Note that *preferred* here does not necessarily mean *best*. Every decision is made under risk. The goal of any analysis where values are estimated, uncertain, or knowledge is incomplete should be to make the best decision given the information available, which may not necessarily be the best decision objectively.

Table 5. Results from EDGe$ analysis using point estimates

	Retrofit	New Bridge
Disaster Economic Benefits		
Response and Recovery Costs	$630 865	$1 051 442
Direct Loss Reduction	$273 375	$0
Indirect Losses	$2 102 883	$3 680 045
Disaster Non-Market Benefits		
Value of Statistical Lives Saved	$788 581	$1 577 162
Number of Statistical Lives Saved	0.2	0.4
Non-disaster Related Benefits		
One-Time	$0	$0
Recurring	$0	$2 550 917
Costs		
Direct Costs	$3 000 000	$6 750 000
Indirect Costs	$500 000	$295 000
OMR		
One-Time	$0	$0
Recurring	$0	$732 368
Externalities		
Positive		
One-Time	$0	$0
Recurring	$0	$3 984 762
Negative		
One-Time	$0	$0
Recurring	$0	$0
Present Expected Value		
Benefits	$3 795 704	$8 859 566
Costs	$3 500 000	$7 777 368
Externalities	$0	$3 984 762
With Externalities		
Net (NPV)	$295 704	$5 066 960
Benefit-to-Cost Ratio	1.08	1.65
Internal Rate of Return (%)	3.45	6.37
Return on Investment (%)	0.17	1.30
Non-Disaster ROI (%)	-2.00	-0.32
Without Externalities		
Net (NPV)	$295 704	$1 082 198
Benefit-to-Cost Ratio	1.08	1.14
Internal Rate of Return (%)	3.45	3.79
Return on Investment (%)	0.17	0.28
Non-Disaster ROI (%)	-2.00	-1.34

If the analysis is run under uncertainty, Table 6 and Table 7 are obtained. *Lower* and *Upper* bounds represent those values required for a 95 % prediction interval, i.e. 95 % confidence interval on the output values from the simulation. They are not confidence intervals on the mean. The point estimate in not the mean of the simulations, but the result of the point estimate calculations summarized in Table 5.

Adding uncertainty complicates interpretation. While the additional information more accurately reflects the potential range of outcomes, it also means that choices must be made balancing risk and desired outcome. An alternative with a higher mean *NPV* but a large range of uncertainty may not be as attractive as an alternative with a lower *NPV* but a smaller range of uncertainty.

Table 6 Intermediate Results from EDGe$ under uncertainty[17]

	Retrofit			New Bridge		
	PE	**Lower Bound**	**Upper Bound**	**PE**	**Lower Bound**	**Upper Bound**
Disaster Economic Benefits						
Response and Recovery Costs	$630 865	$258 965	$1 000 580	$1 051 442	$455 623	$1 668 008
Direct Loss Reduction	$273 375	$112 355	$429 260	$0	$0	$0
Indirect Losses	$2 102 883	$856 638	$3 331 145	$3 680 045	$1 468 572	$5 812 145
Disaster Non-Market Benefits						
Value of Statistical Lives Saved	$788 581	$788 581	$788 581	$1 577 162	$1 577 162	$1 577 162
Number of Statistical Lives Saved	0.20	0.20	0.20	0.40	0.40	0.40
Non-disaster Related Benefits						
One-Time	$0	$0	$0	$0	$0	$0
Recurring	$0	$0	$0	$2 550 917	$1 941 394	$2 828 638
Costs						
Direct Costs	$3 000 000	$2 910 188	$3 691 765	$6 750 000	$6 658 530	$7 906 460
Indirect Costs	$500 000	$488 429	$708 031	$295 000	$290 961	$343 936
OMR						
One-Time	$0	$0	$0	$0	$0	$0
Recurring	$0	$0	$0	$732 368	$649 642	$859 790
Externalities						
Positive						
One-Time	$0	$0	$0	$0	$0	$0
Recurring	$0	$0	$0	$3 984 762	$3 231 144	$4 767 689
Negative						
One-Time	$0	$0	$0	$0	$0	$0
Recurring	$0	$0	$0	$0	$0	$0

[17] These values will differ based on the selected “Seed” and “Monte Carlo Bounds Tolerance” values on the “Analysis Information” pages

Table 7 Economic Indicators from EDGe$ under uncertainty[18]

	Retrofit			New Bridge		
	PE	Lower Bound	Upper Bound	PE	Lower Bound	Upper Bound
Present Expected Value						
Benefits	$3 795 704	$2 486 168	$5 097 075	$8 859 566	$6 426 767	$11 035 205
Costs	$3 500 000	$3 454 379	$4 283 494	$7 777 368	$7 701 736	$8 991 533
Externalities	$0	$0	$0	$3 984 762	$3 231 144	$4 767 689
With Externalities						
Net (NPV)	$295 704	($1 402 227)	$1 358 079	$5 066 960	$1 861 184	$6 888 628
Benefit-to-Cost Ratio	1.08	0.64	1.38	1.65	1.23	1.86
Internal Rate of Return (%)	3.45	0.86	4.88	6.37	4.21	7.32
Return on Investment (%)	0.17	-0.71	0.76	1.30	0.45	1.72
Non-Disaster ROI (%)	-2.00	-2.00	-2.00	-0.32	-0.72	-0.19
Without Externalities						
Net (NPV)	$295 704	($1 402 227)	$1 358 079	$1 082 198	($1 883 739)	$2 826 110
Benefit-to-Cost Ratio	1.08	0.64	1.38	1.14	0.78	1.35
Internal Rate of Return (%)	3.45	0.86	4.88	3.79	1.58	4.92
Return on Investment (%)	0.17	-0.71	0.76	0.28	-0.43	0.71
Non-Disaster ROI (%)	-2.00	-2.00	-2.00	-1.34	-1.53	-1.30

Looking at the Riverbend analysis, while the point estimates for the *NPV* without externalities for the *New Bridge* is higher, its lower bound is less than the lower bound of the retrofit. Considering the higher point estimate and upper bound for the alternative, the indication is that there is a larger amount of uncertainty in the *New Bridge* option, due to the increased construction costs and their associated uncertainties. In this case the decision becomes difficult and may depend on the risk preference of the decision maker or require further analysis.[19] The other economic indicators are not useful in this instance either.

In this example, if externalities are included the decision once again becomes trivial. The *NPV* with externalities is consistently higher in its 95 % prediction interval and does not become negative in that range. In the presence of the assumed externalities, the *New Bridge* is the best option.

6 References

Bhatt and Martinez (2013). "Bridge Collapse Could Have Major Economic Implications for Region". The Seattle Times. May 28.

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[18] These values will differ based on the selected "Seed" and "Monte Carlo Bounds Tolerance" values on the "Analysis Information" pages

[19] Future versions will also report the mean of the simulations, allowing for a better understanding of the central tendencies and overall skew of the distribution of simulated results. Histogram representations of the simulated results are also being examined.

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