Wastewater Treatment Plant Upgrade

SYST 573

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Hary Nayer, Vincent Torres, Ben Zevin

Executive Summary

This report discusses a risk analysis conducted to determine best option to implement in order to upgrade a wastewater treatment plant's septage receiving facilities. Within this report an influence diagram and decision tree were developed analyzing three different septage processing systems. Furthermore, various methods of analysis were conducted in order to examine the impact of different factors during the lifetime of the project had on the overall project decision. These factors pertained to qualities such as capital costs, schedule, and performance. Various methods of risk analysis were used to determine the impact these factors could have when considering the impact of perfect information, the probabilities of certain risks occurring, and the possible severities of these risks. This report discusses the objectives of the project in order to develop utilities and better aid in the decision-making process. Finally, upon the completion of this analysis a final decision was made determining the best option to build.

Within assignment 1 the background and objectives of the problem are discussed. As mentioned before the objective of this project is to implement risk analysis and determine the best septage receiving facility to build that meets stakeholder needs such as cost, schedule, and performance. These stakeholders are composed of design engineers, contractors, plant engineering/operations/maintenance staff, and the community for which the plant services.

Assignment 2 discusses the three options to be considered for construction: Enviro-Care Flo Beast, the Lakeside Raptor SAP, and the Lakeside Raptor SCP. Each of these options varies in construction cost, construction time, performance ability, and overall maintenance/operation. An influence diagram was developed considering many of the factors that impact this decision such as capital costs, lifecycle costs, labor quality, and performance. A sensitivity analysis was conducted to determine the impact each of these factors would have on the project payoff. Finally, a decision tree was built around these qualitative factors and the initial construction decision was determined to be the Lakeside Raptor SAP.

Assignment 3 discusses sources of uncertainty that can impact the project and the decisions made. The uncertainties analyzed were labor quality, delays, interest rates, and violations. Ultimately these uncertainties did not change the project choice of the Lakeside Raptor SAP. This is because each of the uncertainties affects each option equally therefore factors such as capital costs and schedule remain more significant in the decision-making process. Although the option selected did not change it was determined that if the uncertainties varied across each option there may be a change in the overall option selected. However, that was not the case in this analysis most likely due to the lack of external data and the assumption of a normal distribution for the probabilities of all uncertainties.

Assignment 4 discusses the implementation of probability distribution to analyze some of the risks and uncertainties of this project. This includes the analysis of a normal distribution for labor quality, exponential distribution for project delays, and a binomial distribution for project violations. A normal distribution was used to examine labor quality as magnitude good labor quality has on a project as compared to bad labor quality is comparable. An exponential distribution was used to analyze the probability and impact of project delays on the project timeline. This was the chosen distribution as delays typically build upon one another and the latest delay cannot be addressed until the previous one is. Lastly a binomial distribution was used to analyze the effect project violations on the construction of the facility. A binomial distribution was selected because the probability of having an OSHA violation increases as more labor hours are worked. Overall, each of these distributions did not alter the initial decision made. For each distribution it was found that the most likely probable event to occur was the one that negatively impacted the project the least. Similarly, we didn't expect a change in the initial decision as the probability of the worst occurrence happening doesn't carry a cost impact as significant to factors such as capital costs and life cycle costs.

Assignment 5 discusses the usage of utility functions to determine the optimal wastewater treatment facility design using three decisions and their probabilities: hourly wages ($/hr.), capital investment and investment in safety equipment per employee ($/employee). These decisions were analyzed using independent decision trees to visualize the optimal choice that maximized each value accounting for the certainty equivalents and probabilities.

For assignment 6 an objectives hierarchy was developed in order produce utility functions for each of our objectives. The objectives that composed the hierarchy were to minimize costs, maximize performance, minimize construction time, and minimize fees. Utility models were built for each attribute using swing weights. The utility functions were implemented within our influence diagram and a statistical analysis was conducted to determine the impact each attribute had on a given objective. Furthermore, a decision tree was built considering the utility models and the decision remained the Lakeside Raptor SAP.

Ultimately the risk analysis conducted as part of this project supported the decision of constructing the Lakeside Raptor SAP receiving facility. At each point during analysis the Lakeside Raptor SAP was the ideal system to construct. This decision is further supported by the consistency of the results at each step of analysis. As the initial influence diagram as the basis analysis of risks and probabilities did not impact the initial decision enough to change it. This is most likely due to the significance that capital cost held in the analysis of this project. Similarly, as many of the factors didn't change significantly across other options as compared to capital cost, timeline, and performance it was likely that the Lakeside Raptor SAP would continue to be the best option as it excels in these categories. Overall, this project better aided in the decision-making process as various factors that impact a project were analyzed dynamically showing the degree and probability that a given occurrence can impact the project.

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Project Assignment 1

Assignment Assumptions

- Costs and design specifications come from the *Septage receiving Facility Upgrade Preliminary Engineering Report* developed for the Upper Occoquan Service Authority in Centreville, Virginia.
- We assumed that if the treatment facility didn't pass regulatory tests, it couldn't begin operations.
- We assumed the treatment facility with more technology takes longer to construct but has better performance.
- We assume that cost is the most important factor in making this decision due to the initial report we are obtaining our information from.

Assignment Response

The background of this project revolves around a wastewater treatment plant that plans to implement sewage receiving facilities that allow septic companies to unload their trucks for processing at the wastewater facility. Sewage/septage receiving facilities typically process this waste by grinding up the septage, separating heavy solids, mixing the slurry that remains and pumping it to the head of the main water treatment plant. Equipment and infrastructure used to run such a facility can range in size and sophistication. Determining the design of such a facility brings in many factors. The objective of this project is to determine the best method to upgrade a septage receiving facility such that it will meet the requirements to process septage, requires reasonable maintenance, comes at a fair cost, and can be completed within a practical timeline.

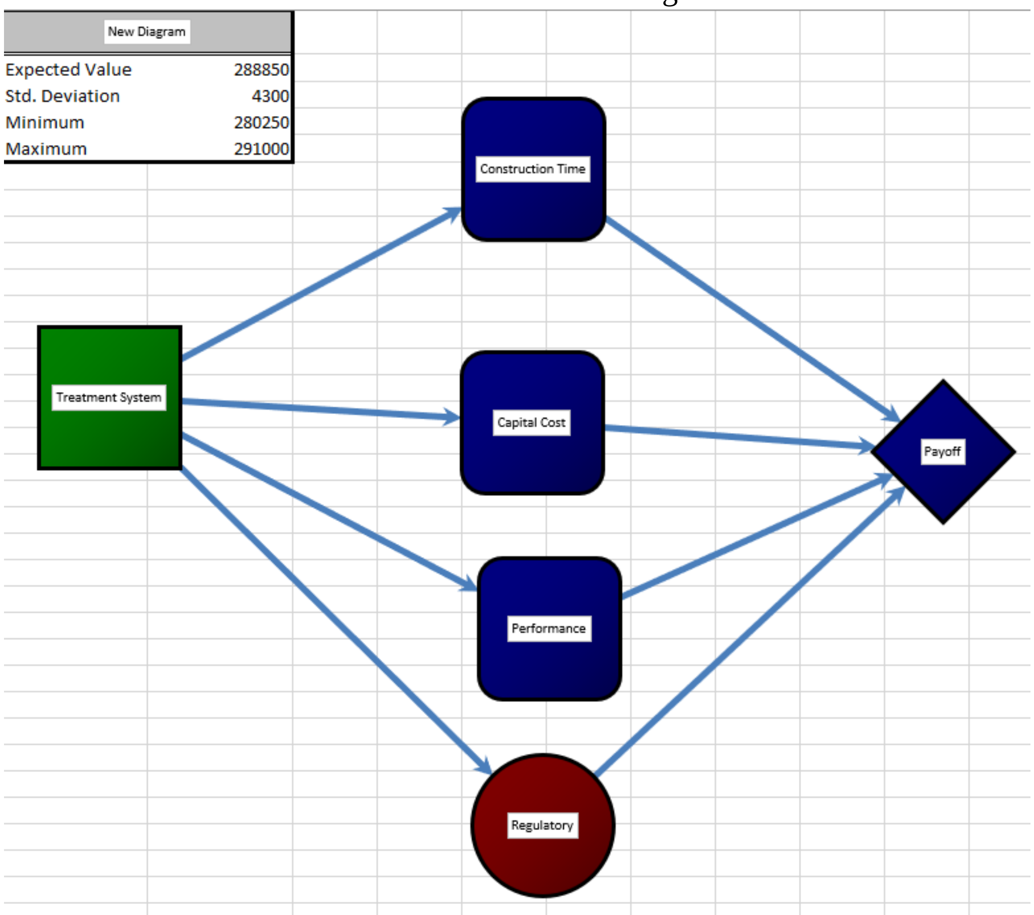
The project objectives center around producing the best upgraded system possible at a reasonable cost, within a reasonable timeline, and with adequate performance. These objectives consist of factors such as updating infrastructure to code, upgrading automation and control system technology, ensuring operability with as little operator interference, and ensuring the cost and schedule of this project does not negatively impact stakeholders.

The stakeholders of this problem consist of individuals both involved in the daily use of such a facility to the community for which the facility services. The main stakeholders for this type of project are the ratepayers and community. The bonds used to pay for a project of this magnitude may impact their sewage rates. Similarly other stakeholders are composed of the plant operation staff. They will be responsible for running the facility once complete and will also be responsible for maintenance. Some of the stakeholders that are also decision makers are the contractors, plant engineers, and plant operations staff. All these groups are responsible for making decisions such as developing standards of operations, deciding which type of facility is best to construct, and developing infrastructure that fits the needs of other stakeholders.

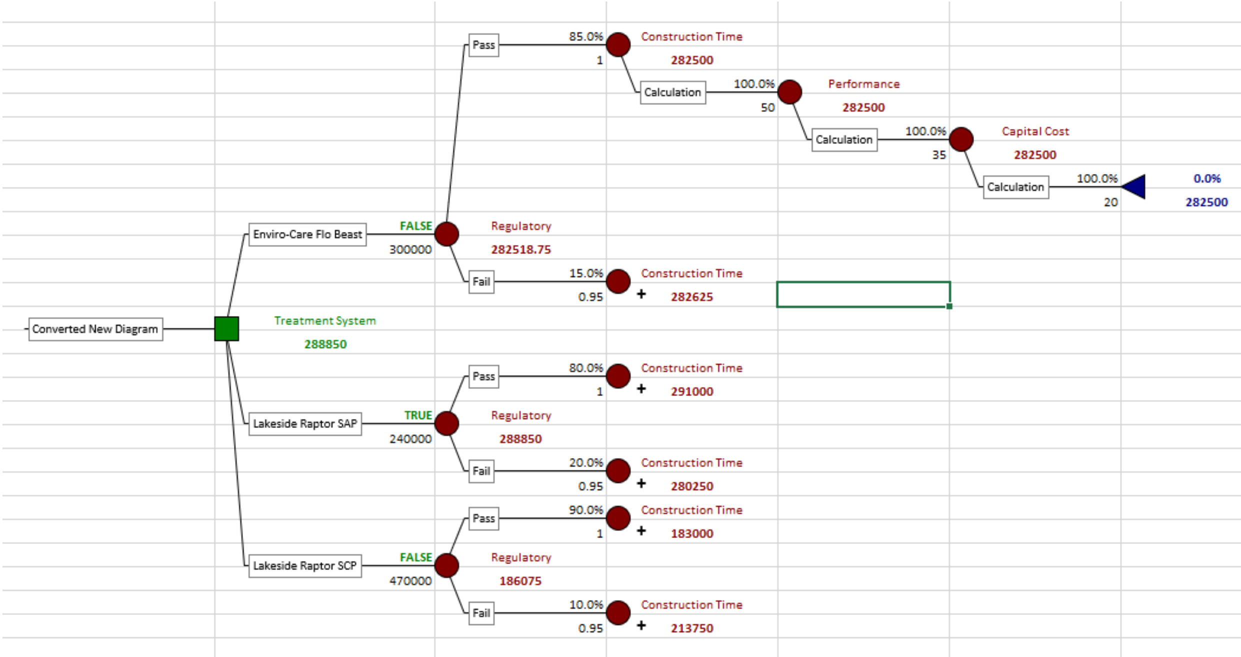
The main uncertainties in this project affect the construction of the facility as well as the operations. For example, one of the most significant uncertainties is meeting the project schedule on time and staying within budget. These can be affected by factors such as delays, supply chain issues, labor disputes, natural disasters, operations disruptions, and staffing issues. Within the scope of this analysis the three largest uncertainties will be delays, labor qualities, and violations during construction. These uncertainties can affect capital costs and construction time during the project and performance and lifecycle cost once the project is completed.

This project encompasses various methods of analysis which aided the group in determining the best facility to build. These methods of analysis consisted of developing decision trees, sensitivity analysis, probability analysis, utility, and risk analysis. Within this project three construction solutions and their components are evaluated to determine the best construction option.

Initial Influence Diagram



Initial Decision Tree



Conclusions/Lessons Learned

From our initial influence diagram and decision tree, the best option is the Lakeside Raptor SAP, with the Enviro-Care Flo Beast very close behind it. These results are very similar to the results in the Septage receiving Facility Upgrade Preliminary Engineering Report. From this assignment be gained a better understanding of how Precision Tree works and how to build influence diagrams and decision trees. We also learned that it is essential to write down the initial problem and identify key factors in chronological order so everyone can be on the same page about where we want to take the project.

Project Assignment 2

<u>Assignment Assumptions</u>

- Costs and design specifications come from the *Septage receiving Facility Upgrade Preliminary Engineering Report* developed for the Upper Occoquan Service Authority in Centreville, Virginia.
- Assumed that the major cost drivers for the sensitivity analysis were capital costs, life cycle costs, performance, and regulatory fines.
- Assumed that each of these factors do not necessarily influence one another but can impact similar calculations in decision making.

<u>Assignment Response</u>

The three options for analysis in this project are derived from a capital project executed by the Upper Occoquan Service Authority in Centerville, Virginia. Three main options to address the septage receiving facility upgrade were the Enviro-Care Flo Beast, the Lakeside Raptor SAP, and the Lakeside Raptor SCP. The Envio-Care Flow Beast has the lowest construction time however is the least efficient unit with the lowest performance. The lack of performance is mainly due to a design with little automation and more manual operation. The next option is the Lakeside Raptor SAP which has the lowest capital costs, replacement parts cost, and utility cost. The third option is the Lakeside Raptor SCP septage processing unit. It has the largest capital cost, utility cost, and construction time. However, it has the highest septage processing flowrate and septage truck unloading time. It implements a sophisticated automated system to process septage with little operator interaction. Each of these three options serve the purpose of processing septage, but each does so at different costs and methods of operability.

Decision Tree Based on three facility choices

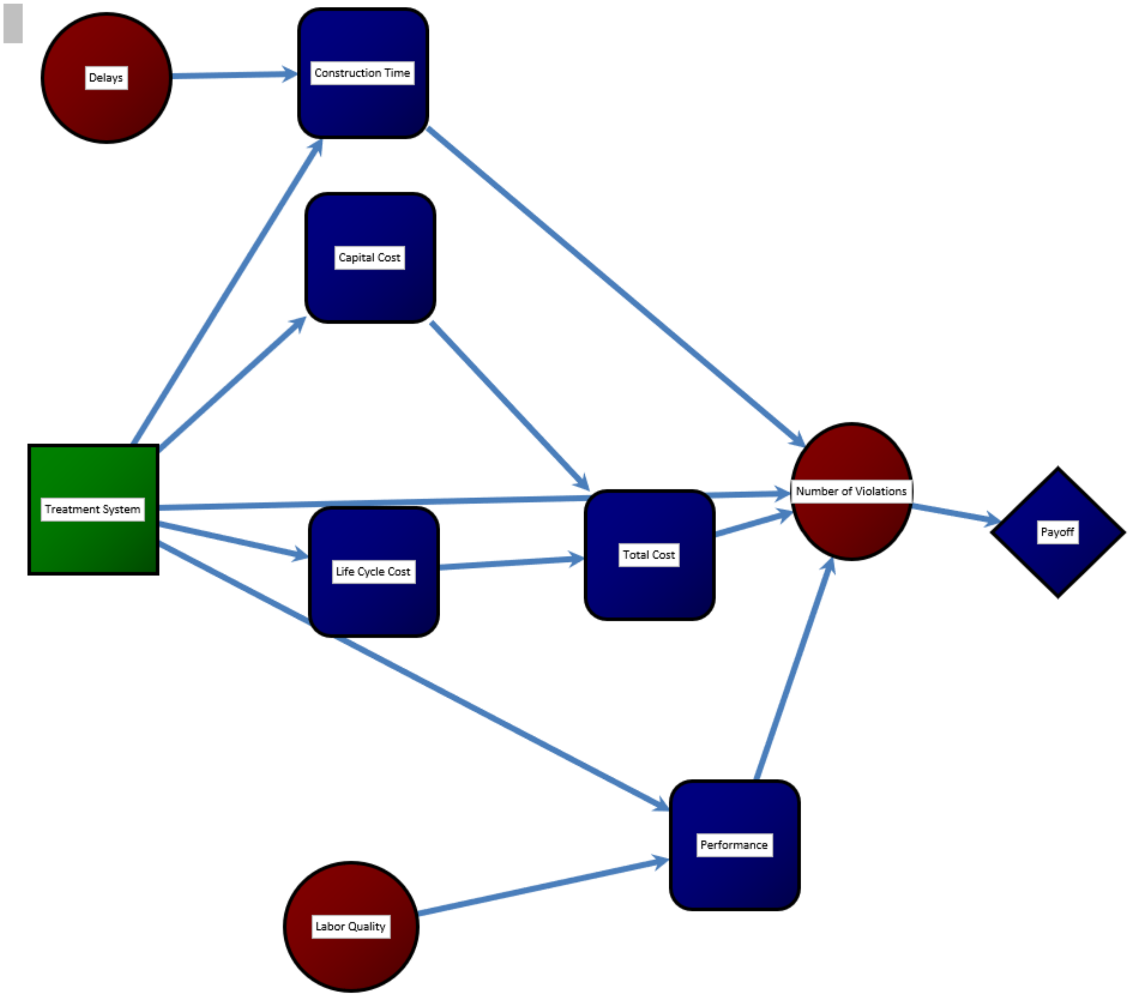


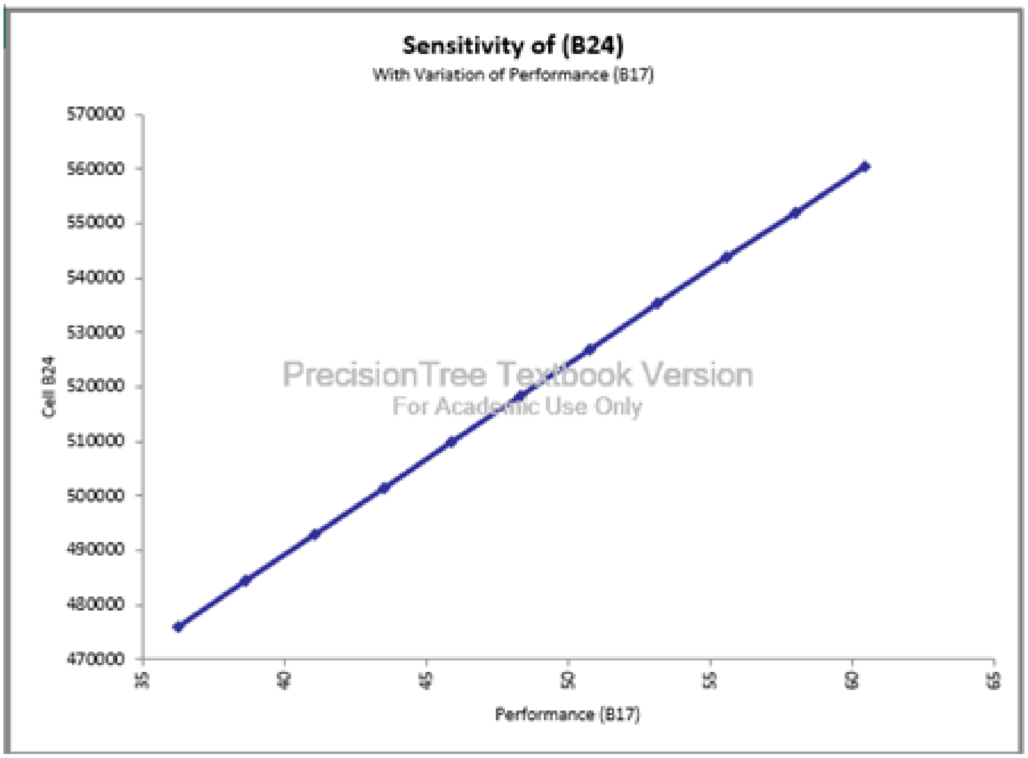
Diagram Less Variables (2) (2)	
Expected Value	665760.1875
Std. Deviation	34859.14525
Minimum	595124.25
Maximum	724719

A decision Tree was developed analyzing various factors that impact the execution of this project to determine which option best fit the needs of the facility. These factors included construction time, capital cost, life cycle cost, and performance. Similarly, the chance nodes were composed of factors which could drastically affect the project's budget or timeline. These chance nodes consisted of labor quality, project delays and number of regulatory violations. It was determined that delays directly impacted construction time and labor quality on the overall performance of the selected option. Lastly the construction time, total cost, and performance directly influenced the number of regulatory violations which could arise from any of these factors overall affecting the payoff and best decision.

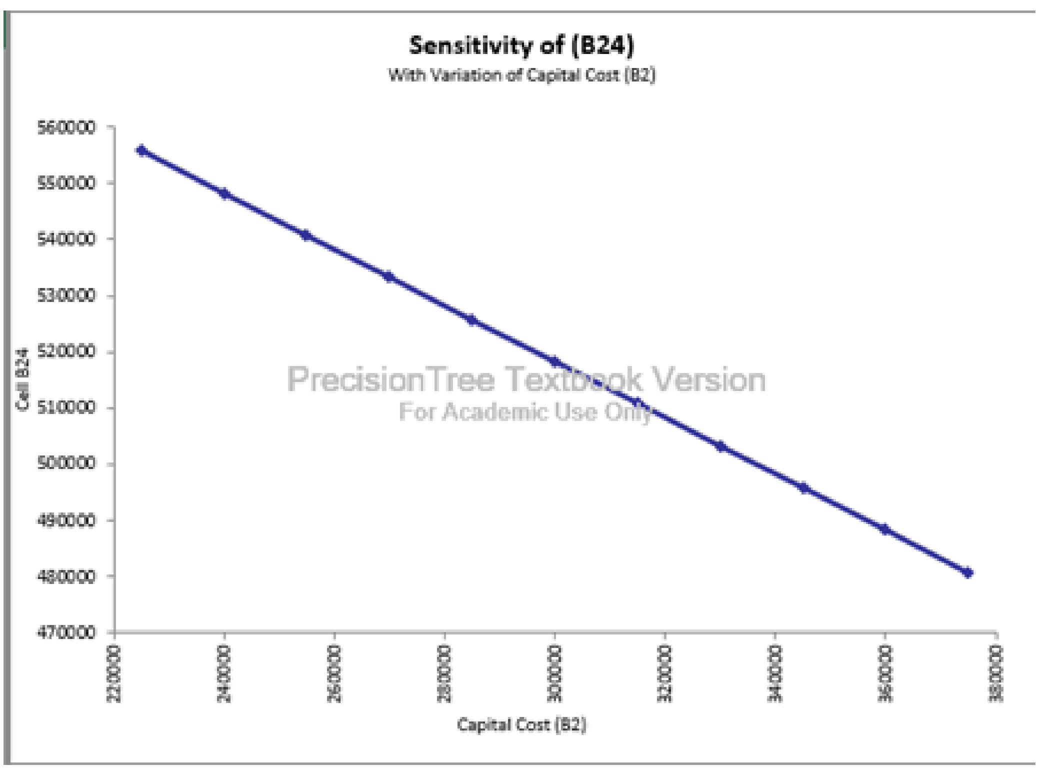
Sensitivity Analysis of Options

	Enviro-Care Flo Beast	Lakeside Raptor SAP	Lakeside Raptor SCP
Capital Cost	300000	240000	470000
Labor Hours	200	200	400
Labor Pay	40	40	40
Labor Cost	8000	8000	16000
Replacement Parts	4000	3500	4000
Utility Cost	1984	992	3500
Life Cycle Cost	160395.0816	143281.9908	269542.65
Total Cost	460395.0816	383281.9908	739542.65
Total Cost Scale	53.96049184	61.67180092	26.045735
Construction Time (months)	18	24	30
Construction Time using formula	62.5	50	37.5
Construction Time	1000	1200	1300
Average Flow Rate	346	402	420
Amax Unloading Time	29	19	17
Performance	48.35	66.45	70.75
Violation calculation	1.4502	1.4502	1.4502
Regulatory Pass Prob	0.15	0.2	0.1
Regulatory Fail Prob	0.85	0.8	0.9
Payoff (Corrected w/ no violation)	532777.4592	615934.0046	434103.675
Payoff (Corrected w/ violation)	518275.4592	601432.0046	419601.675

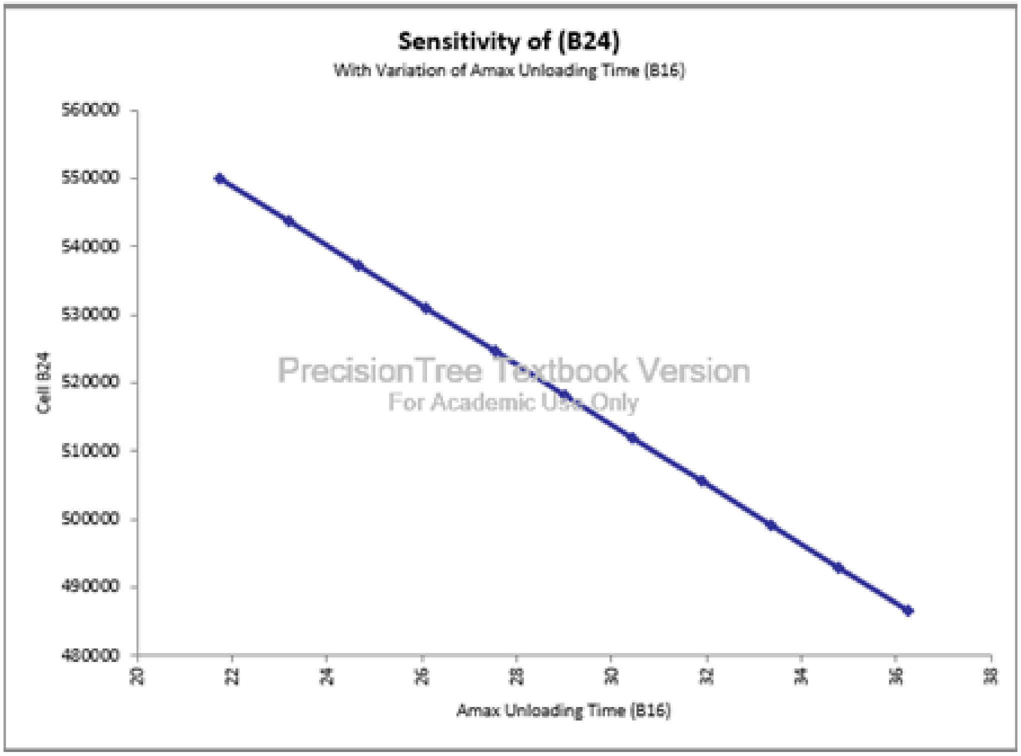
Sensitivity Analysis Performance Vs Payoff



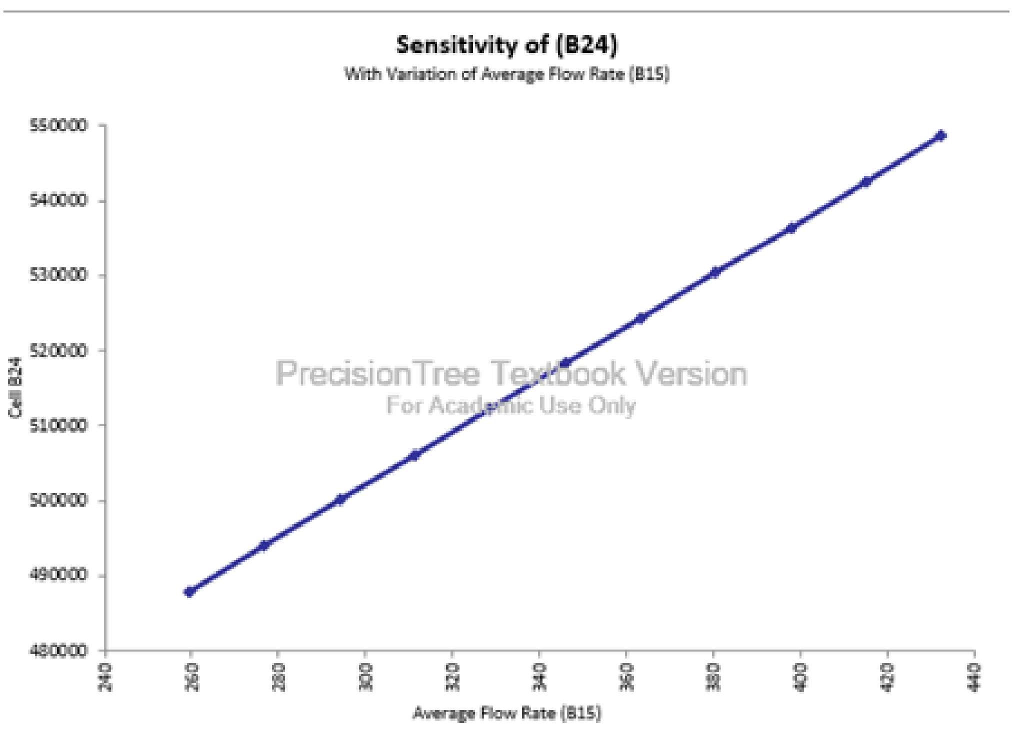
Sensitivity Analysis Capital Costs Vs Payoff



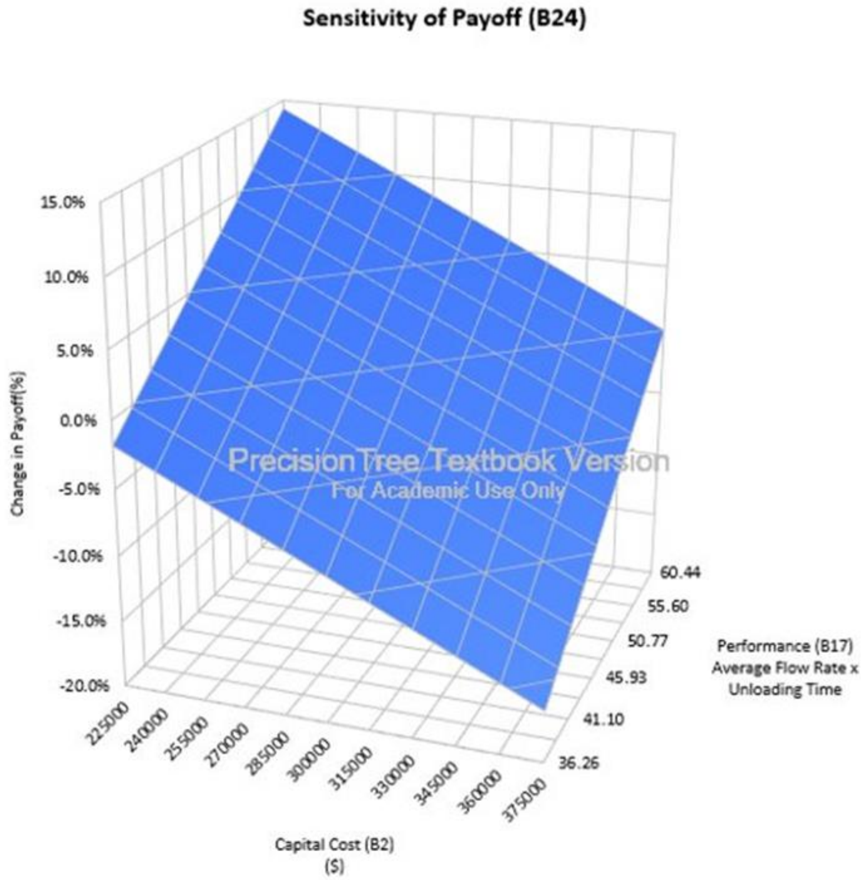
Sensitivity Analysis Septage Unloading Time Vs Payoff



Sensitivity Analysis Average Septate Processing Flow Rate Vs Payoff



Two-Way Sensitivity Analysis Comparing Permeance and Capital Costs

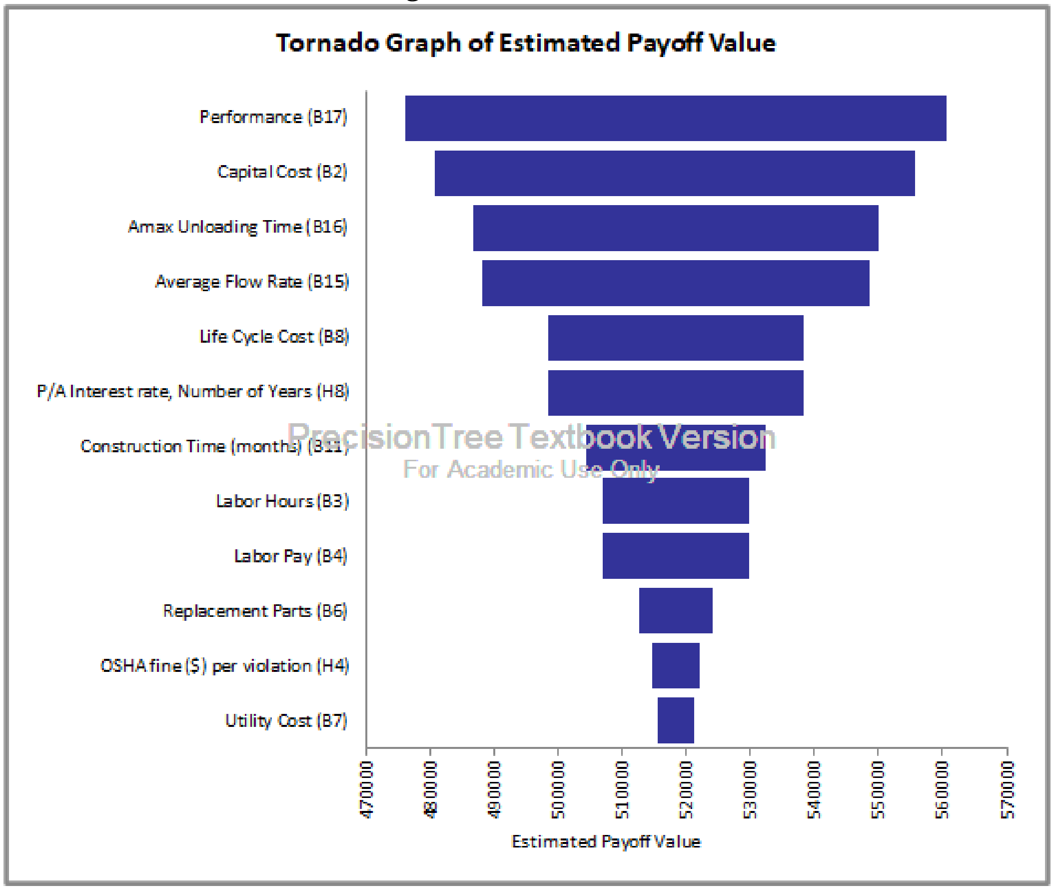


Two-Way Sensitivity Data of Payoff (B24)
With Variation of Capital Cost (B2) and Performance (B17)

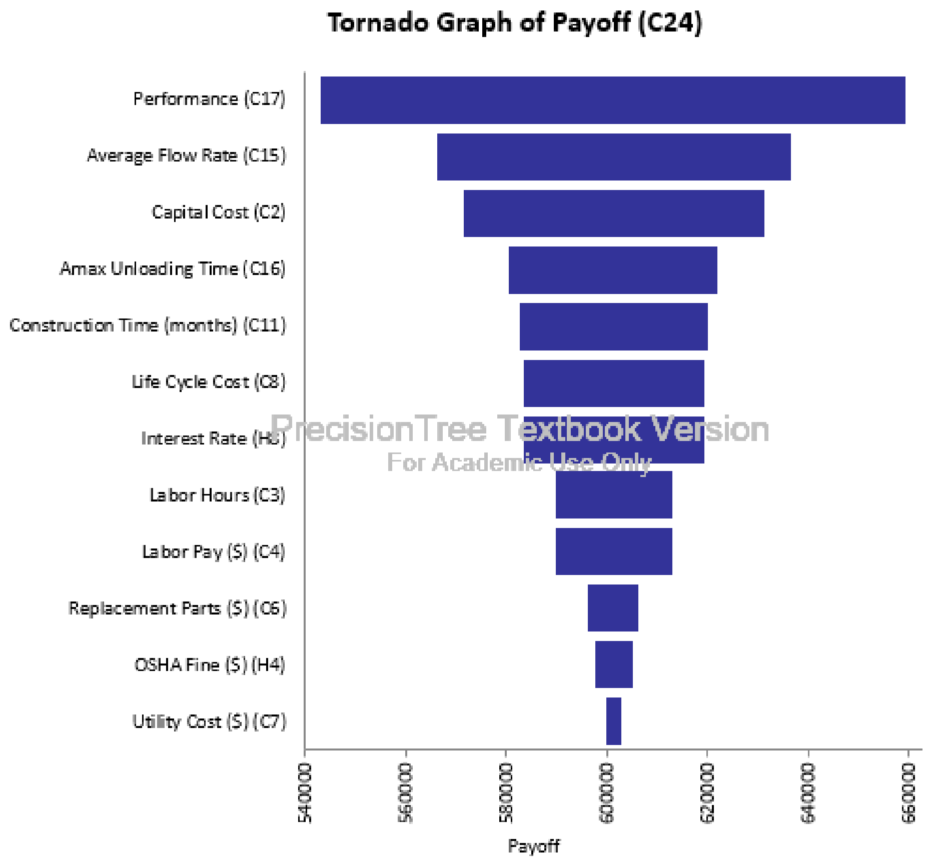
		Capital Cost (B2)										
		225000	240000	255000	270000	285000	300000	315000	330000	345000	360000	375000
Performance (B17)	36.26	-1.8377%	-3.2715%	-4.7053%	-6.1391%	-7.5729%	-9.0067%	-10.4405%	-11.8743%	-13.3082%	-14.742%	-16.1758%
	38.68	-0.2201%	-1.6539%	-3.0877%	-4.5215%	-5.9553%	-7.3891%	-8.823%	-10.2568%	-11.6906%	-13.1244%	-14.5582%
	41.10	1.3975%	-0.0363%	-1.4701%	-2.9039%	-4.3378%	-5.7716%	-7.2054%	-8.6392%	-10.073%	-11.5068%	-12.9406%
	43.52	3.0151%	1.5813%	0.1474%	-1.2864%	-2.7202%	-4.154%	-5.5878%	-7.0216%	-8.4554%	-9.8892%	-11.323%
	45.93	4.6326%	3.1988%	1.765%	0.3312%	-1.1026%	-2.5364%	-3.9702%	-5.404%	-6.8378%	-8.2717%	-9.7055%
	48.35	6.2502%	4.8164%	3.3826%	1.9488%	0.515%	-0.9188%	-2.3526%	-3.7865%	-5.2203%	-6.6541%	-8.0879%
	50.77	7.8678%	6.434%	5.0002%	3.5664%	2.1326%	0.6987%	-0.7351%	-2.1689%	-3.6027%	-5.0365%	-6.4703%
	53.19	9.4854%	8.0516%	6.6178%	5.1839%	3.7501%	2.3163%	0.8825%	-0.5513%	-1.9851%	-3.4189%	-4.8527%
	55.60	11.1029%	9.6691%	8.2353%	6.8015%	5.3677%	3.9339%	2.5001%	1.0663%	-0.3675%	-1.8013%	-3.2352%
	58.02	12.7205%	11.2867%	9.8529%	8.4191%	6.9853%	5.5515%	4.1177%	2.6839%	1.25%	-0.1838%	-1.6176%
	60.44	14.3381%	12.9043%	11.4705%	10.0367%	8.6029%	7.1691%	5.7352%	4.3014%	2.8676%	1.4338%	0.0%

A sensitivity analysis was conducted on the major cost driver of this project: performance, capital costs, septage unloading time, and septage processing flow rate. Ultimately the results of the sensitivity analysis align with what was expected. It was expected that at higher performance and higher flowrates the system would have a better payoff. Similarly, it was expected that as capital costs rose or if septage unloading times were high the payoff of the options of fall. A two-way sensitivity analysis was conducted between performance and capital costs and the impact on payoff. As expected, when both factors increased a decrease in the overall payoff was observed.

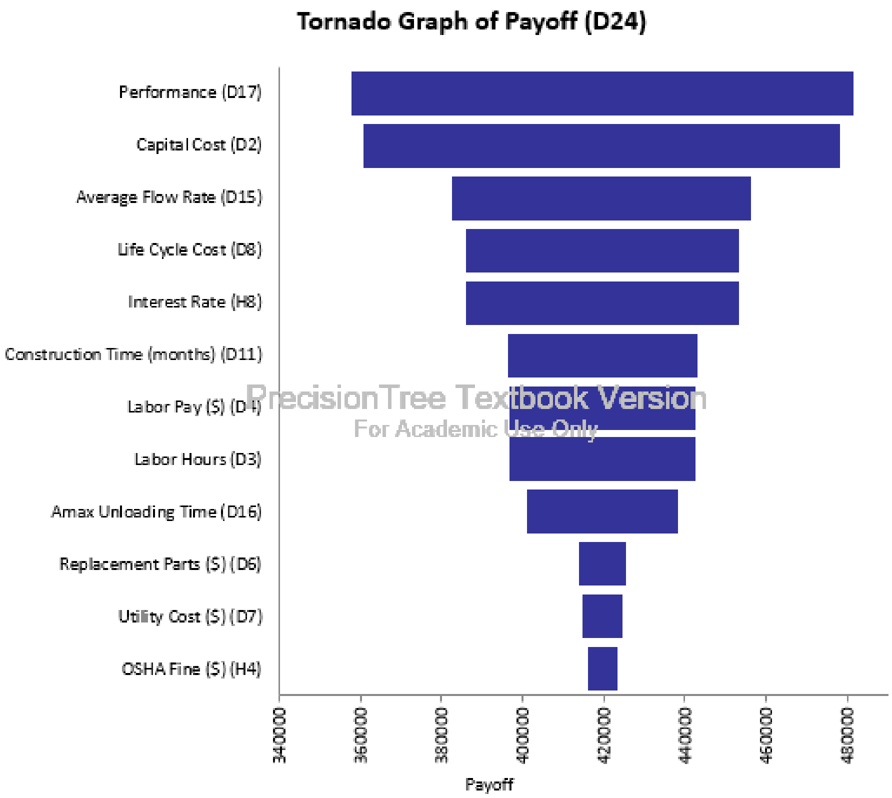
Tornado Diagram for Enviro-Care Flo Beast



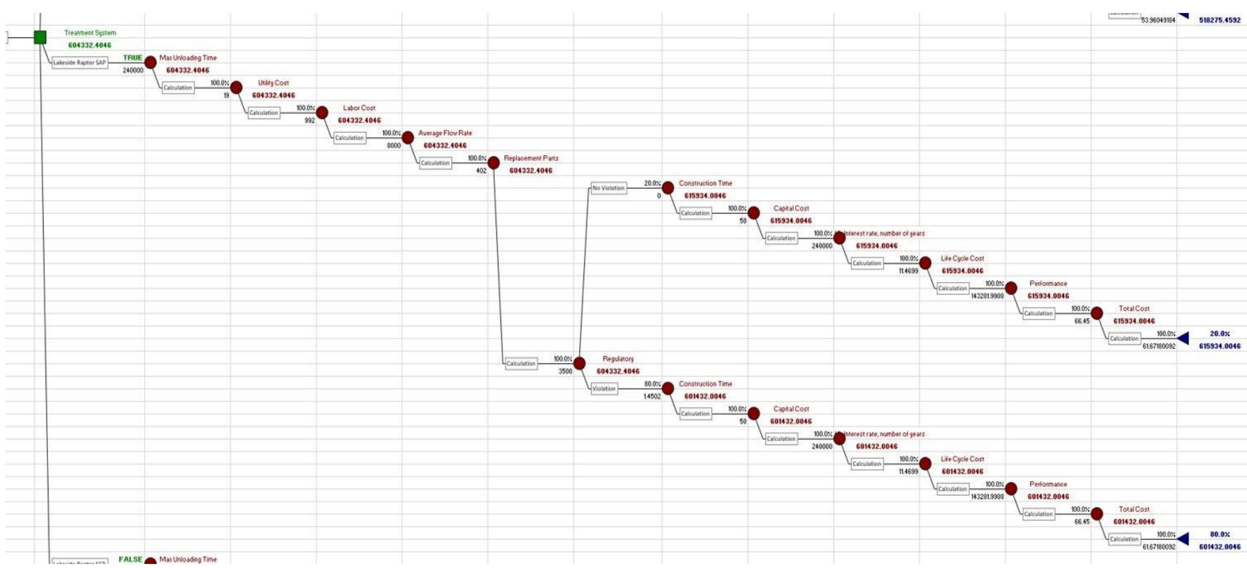
Tornado Diagram for Lakeside Raptor SAP



Tornado Diagram for Lakeside Raptor SCP



Decision Tree (Portion Noting Option Selected)



Tornado diagrams were developed for each of the three options using the influence diagram developed as a basis. It was found for all three options that performance and capital costs were the most significant factors in deciding on the option. This was expected as can vary by a large magnitude and in turn have drastic implications on the functionality of equipment. The same is the case for the average flow rate, another performance metric. Similarly capital cost was a significant factor across all three options. This was mainly due to the significance the actual project cost has on the project as compared to factors such as labor pay, utility costs, and fines. Lastly the lesser impact of factors such as utility costs, replacement parts, and fines was expected. This is because these factors are almost the same across all three options and carry a lower costs impact that other factors.

Conclusions/Lessons Learned

Based on the sensitivity analysis, decision tree and the review of the three outlined options the Lakeside Raptor SAP septage processing unit yields the best payoff. This was expected as performance and capital costs are one of the highest driving factors when making this decision. Similarly, the sensitivity analysis conveyed that As the Lakeside Raptor SAP had the lowest capital cost and comparable unloading and flow rate times to the Lakeside Raptor SCP it became the more obvious choice in analysis. It was expected that factors such as bond interest rate, fines, and replacement part costs had a lesser influence on the decision. This is because these factors are similar if not the same across all options having similar cost implications. Similarly, these factors have lower cost implications as compared to factors such as capital and lifecycle costs.

Project Assignment 3

Assumptions:

- Due to the limitations of the project, only one limitation can affect our decision at a time.
- We assume that employees want to put in good quality work for the chance of getting promoted and to not get fired. This is the reason for the probability distribution of labor quality.
- Construction time and delays are measured in months.
- Delays are yearly averages of time, so delays need to be multiplied by years in construction.
- Interest rates will change drastically over time and the interest rates are the average over a 20-year period.
- We assume that getting over 5 violations is very unlikely and doesn't need to be represented.

Response

The first source of uncertainty we identified is the level of labor quality that will occur during the treatment system's operation. A possible source of information that could give you the results of this uncertainty is a survey of supervisors and employees of the work site or past work sites. This source will provide information on the employees' motivation and how much they enjoy their job. If the survey was perfect and all the responses were truthful, you can accurately determine the labor quality of the treatment plant. If the survey wasn't perfect, we could still get accurate information about labor quality and calculate probability distributions and the different possible quality levels. We identified three levels of this uncertainty: poor, mediocre, and good. If the labor quality were to be poor, there would be a 15% drop in the treatment system's performance. If the labor quality is mediocre, there is no drop or increase in performance, and if there is good labor quality, there is a 20% increase in performance. There is a 25% chance of poor quality, a 40% chance of mediocre quality, and a 35% chance of labor quality.

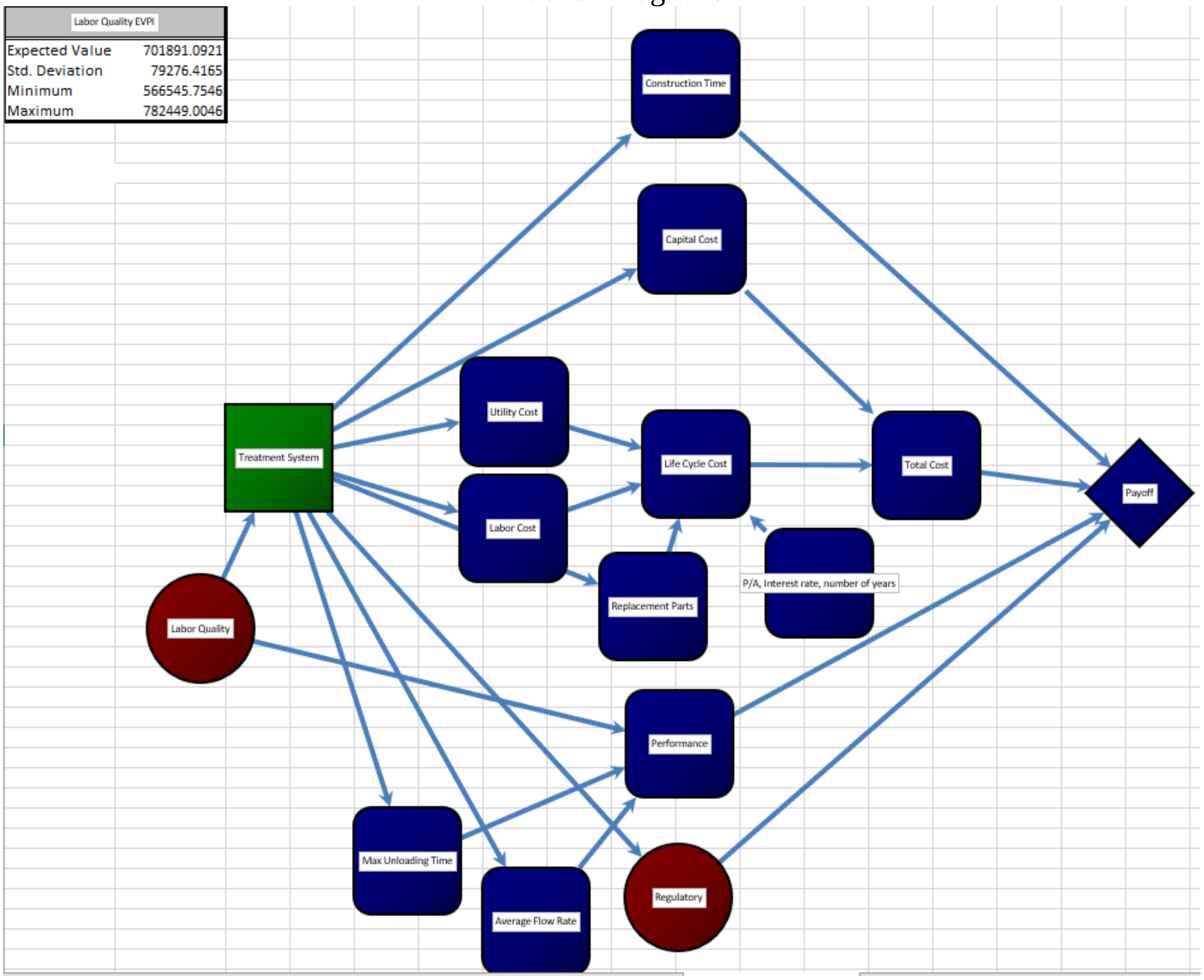
Labor Quality Value Chart:

Labor Quality	Value	Probability
Poor	0.85	0.25
Mediocre	1	0.4
Good	1.2	0.35

Labor Quality EVPI and No EVPI:

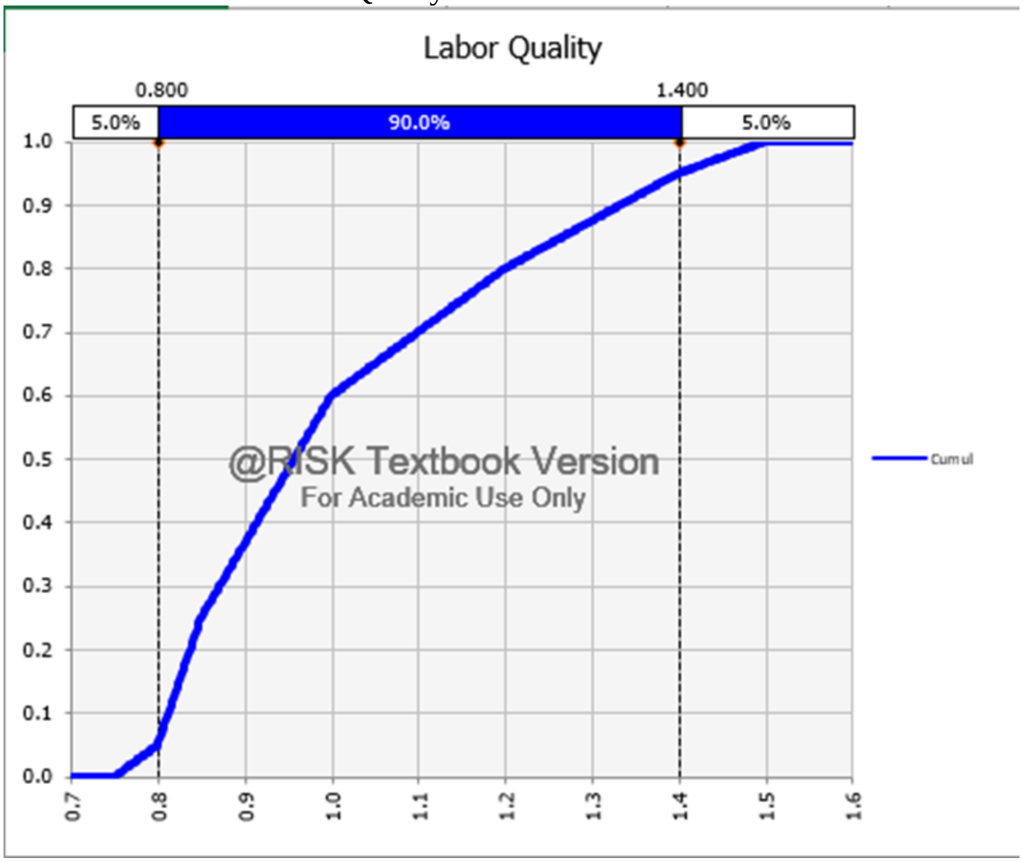
Uncertainty	EVPI	No EVPI
Labor Quality	701891.0921	611890.4675

Influence Diagram:



The value of the perfect source for labor quality is 90,000 because the difference between EVPI and No EVPI is 90,000. Even though the value is still very high, we recommend that you do not buy this source because it doesn't change the model's decision. The uncertainty of the labor quality is independent of the treatment system. The treatment system will not change the labor quality, and the labor quality won't change the system.

Labor Quality Cumulative Distribution



Value	Distribution
0.8	0.05
0.85	0.25
1	0.6
1.2	0.8
1.4	0.95
0.75	Min
1.5	Max

When looking at the decomposition of the labor quality into smaller chunks, you can see that the labor quality distribution is normal, and the cumulative distribution is linear. Because of the normal distribution of labor quality, we can assume that decomposing the labor quality uncertainty won't change the decision of the model. The normal distribution would remain the same no matter how many assessments labor quality was decomposed into.

The second uncertainty identified was delays. A possible source of this information is a computer or system that maps all the supply chain delays of all materials that are required for a specific project. Another source needed for delays is a computer that could accurately predict the weather months in advance to determine the best time to conduct construction or plan around the weather. If the source isn't perfect, it can still give us an accurate guide to create probabilities of expected delays. We identified four categories of this uncertainty, Weather, Supply Chain, Weather and Supply Chain, and no delays. If there are weather delays during the construction of the system, there is expected to be a one-month delay annually. If there is a supply chain delay, there is expected to be a 1.5-month delay annually. If both types of delays are to occur, there will be a 2.5-month delay annually, and finally, with no delays, there will be no added time. There is a 30% chance of weather delays, a 45% chance of supply chain delays, a 15% chance of having both delays, and a 10% chance of having no delays.

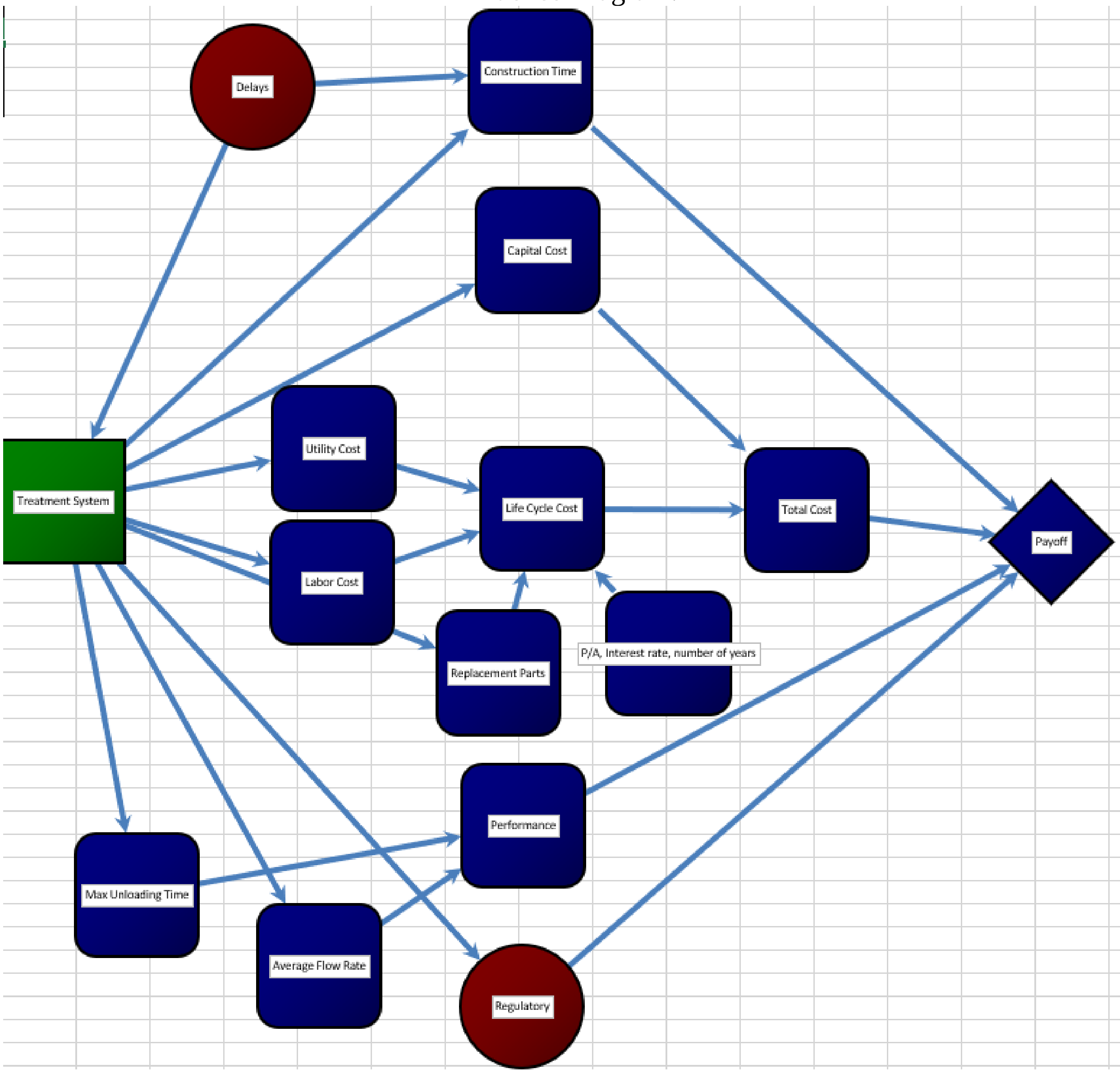
Delays Value Chart:

Delays	Value	Probability
Weather	1	.3
Supply Chain	1.5	.45
Both	2.5	.15
None	0	.1

Delays EVPI and No EVPI:

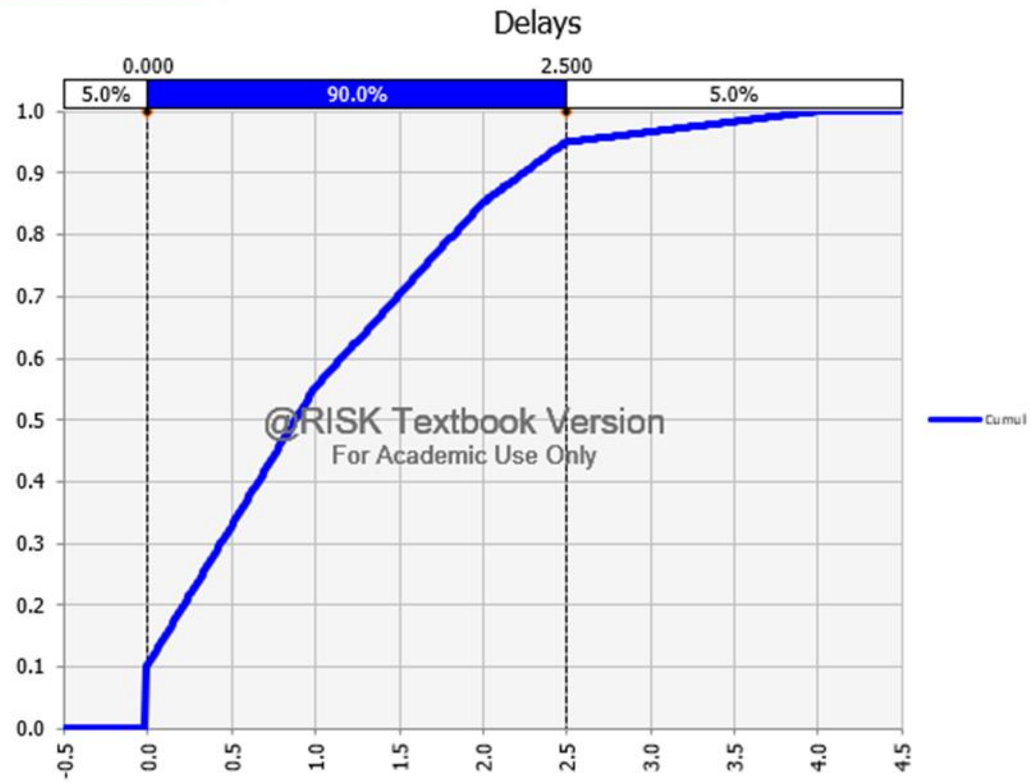
Uncertainty	EVPI	No EVPI
Delays	677911.1546	593442.4046

Influence Diagram:



The value of the perfect source for delays is 79,000 because the difference between EVPI and No EVPI is 79,000. Even though the value is still very high, we recommend that you do not buy this source because it doesn't change the model's decision. The uncertainty of the delays is independent of the treatment system. The treatment system won't change the delays, and the delays won't change the system.

Delays Cumulative Distribution:



Value	Distribution
0	0.1
1	0.55
1.5	0.7
2	0.85
2.5	0.95
0	Min
4	Max

When looking at the decomposition of the delay time into smaller chunks, you can see that the delay time distribution is normal with a small left skew, and the cumulative distribution is linear. Because of the normal distribution of delays, we can assume that further decomposing the delays uncertainty won't change the model's decision. The normal distribution would remain the same no matter how many assessments delays were decomposed into.

The third uncertainty identified was Interest Rate. A possible source that could predict economics is a world-renowned economist or a device that can predict future interest rates. With a device, you could get the exact future interest rates to get the EVPI. Still, if that device didn't exist, you could use the economist to get a prediction and probabilities of future interest rates for the No EVPI. Three possible interest rates were identified, 5%, 6%, and 7%. The 5% interest rate has a 30% probability of occurring, the 6% interest rate has a %50 probability of occurring, and the 7% interest rate has a 20% probability of occurring.

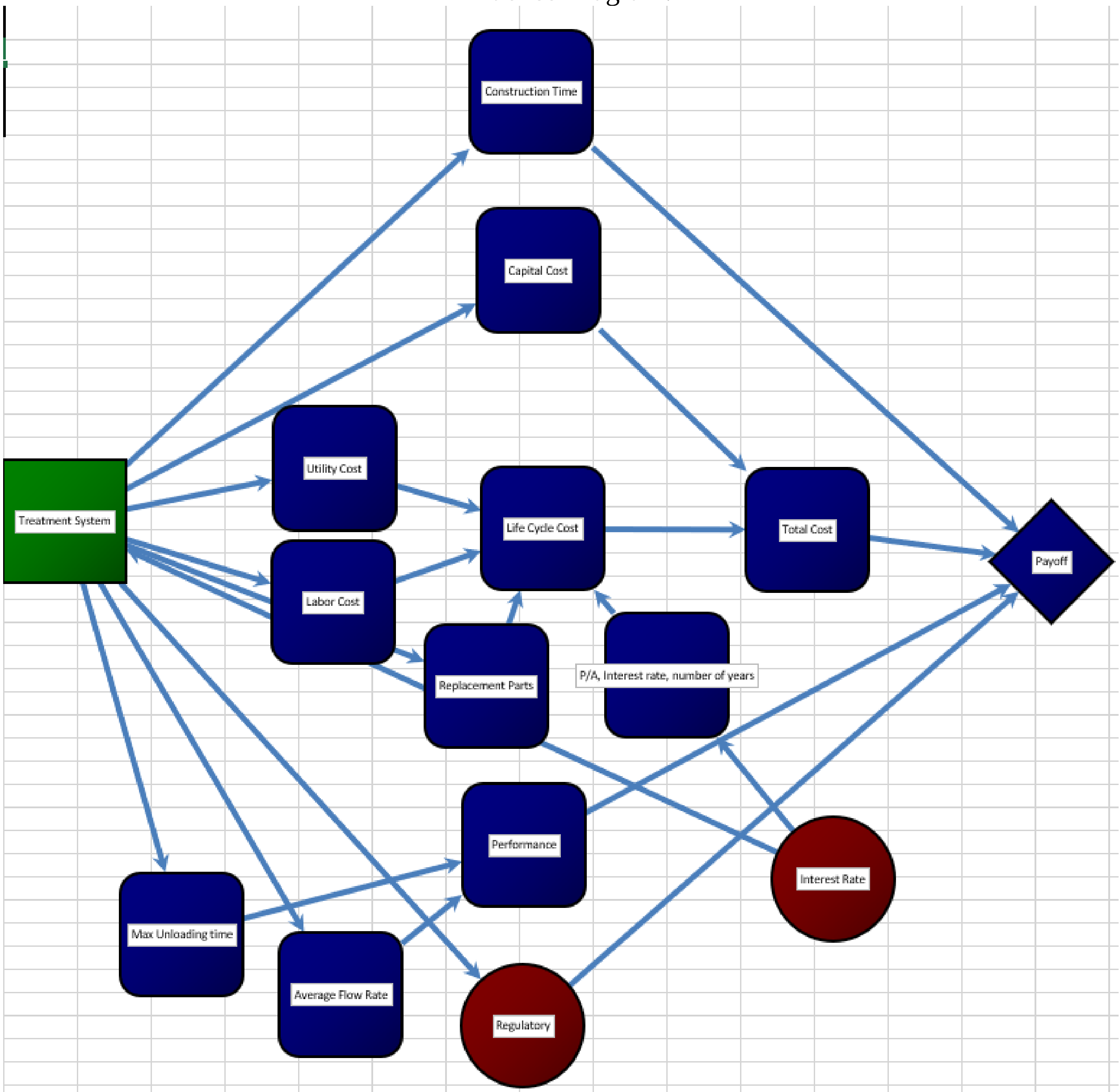
Interest Rate Value Chart:

Interest Rate	Value	Probability
5%	12.462	0.3
6%	11.47	0.5
7%	10.594	0.2

Interest Rate EVPI and No EVPI:

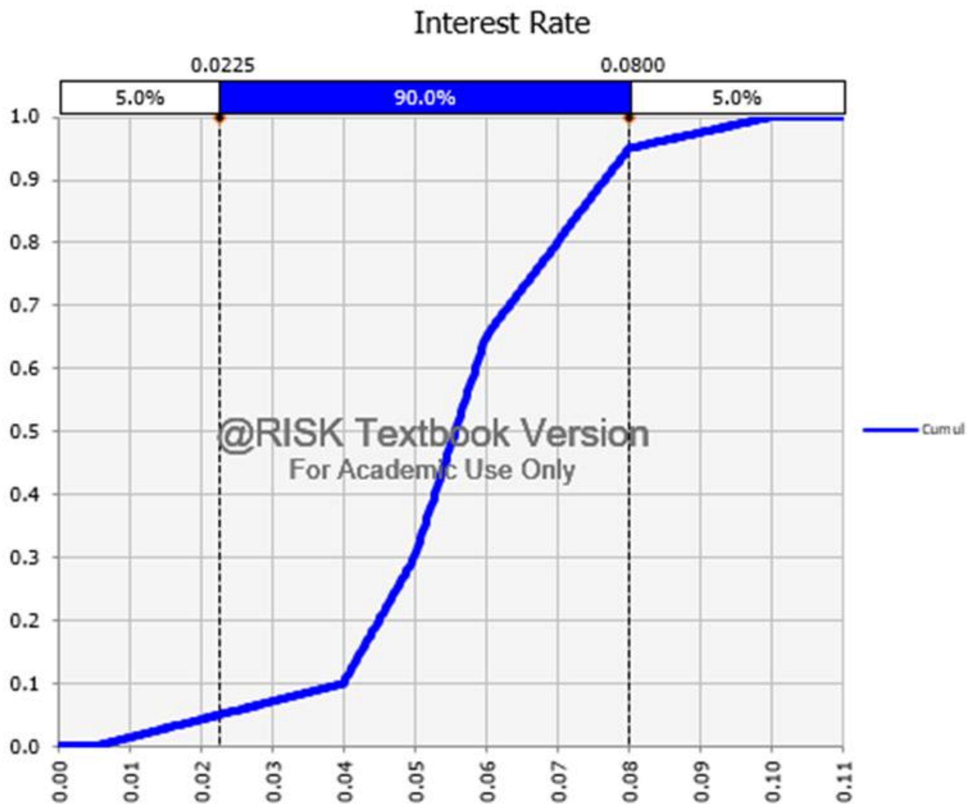
Uncertainty	EVPI	No EVPI
Interest Rate	687567.2696	603567.2696

Influence Diagram:



The value of the perfect source for interest rate is 83,000 because the difference between EVPI and No EVPI is 83,000. Even though the value is still very high, we recommend that you do not buy this source because it doesn't change the model's decision. The uncertainty of the interest rate is independent of the treatment system. The interest rate affects each potential system in the same way. The treatment system won't change the interest rate, and the interest rate won't change the system.

Interest Rate Cumulative Distribution:



Value	Distribution
0.04	0.1
0.05	0.3
0.06	0.65
0.07	0.8
0.08	0.95
0.005	Min
0.1	Max

When looking at the decomposition of the interest rates in smaller chunks, you can see that the interest rates distribution is normal with a smaller standard deviation, and the cumulative distribution is somewhat linear. Because of the normal distribution of interest rates, we can assume that further decomposing the interest rates uncertainty won't change the model's decision. The normal distribution would remain the same no matter how many assessments delays were decomposed into.

The final uncertainty identified is the number of violations. During the construction or operation of a treatment facility, the facility can receive violations mainly from OSHA about working conditions. With these violations, the facility typically must pay a fine and fix the reason for it. A source to determine the number of offenses a facility will receive is the inspection history of the inspector. This information can give you an exact idea of the number of violations he will give out. We identified five levels of the number of violations, and you can be given anywhere from one to five violations at one facility. The likelihood of receiving one violation is 10%, 20% for two, 40% for three, 20% for four, and 10% for five.

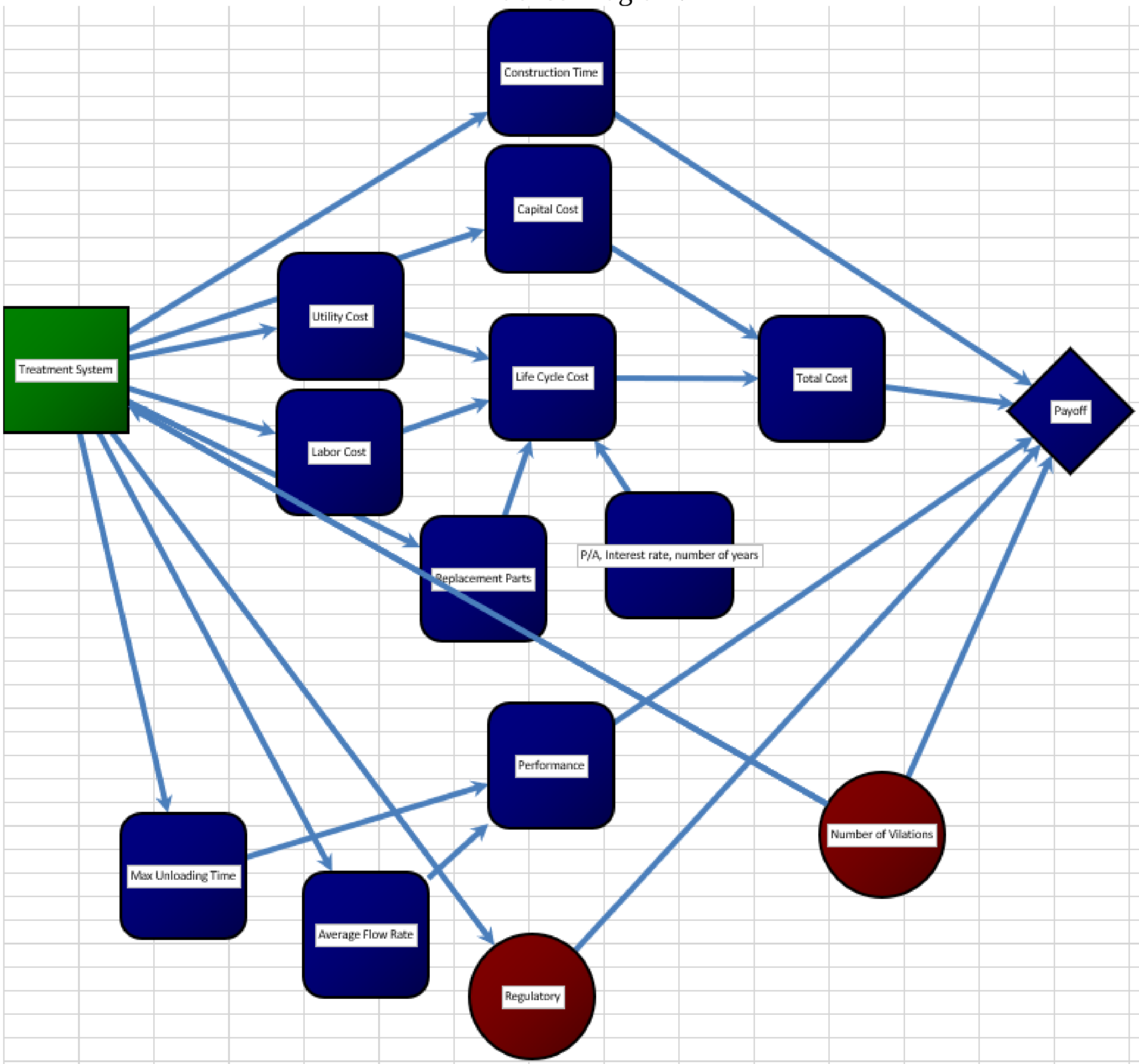
Number of Violations Value Chart:

Number of Violations	Value	Probability
1	1	.1
2	2	.2
3	3	.4
4	4	.2
5	5	.1

Number of Violations EVPI and No EVPI:

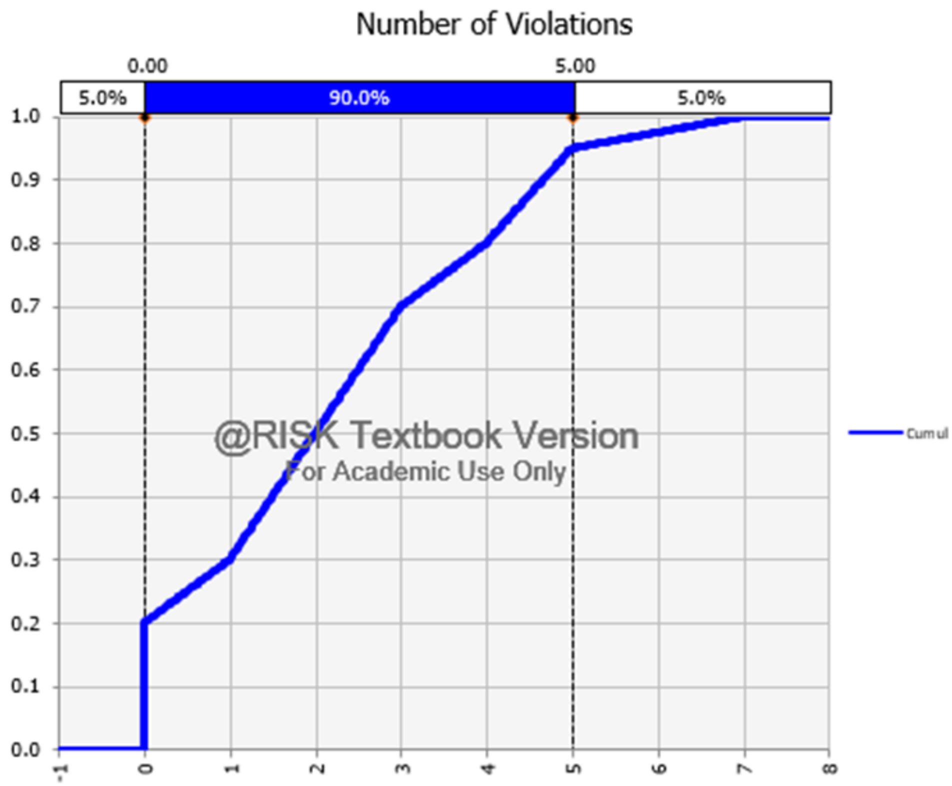
Uncertainty	EVPI	No EVPI
Number of Violations	689129.2046	581129.2046

Influence Diagram:



The value of the perfect source for a number of violations is 85,000 because the difference between EVPI and No EVPI is 85,000. Even though the value is still very high, we recommend that you do not buy this source because it doesn't change the model's decision. The uncertainty of the number of violations is independent of the treatment system. The number of violations affects each potential system in the same way. The treatment system won't change the number of violations, and the number of violations won't change the system.

Number of Violations Cumulative Distribution:



Value	Distribution
0	0.2
1	0.3
2	0.5
3	0.7
4	0.8
5	0.95
0	Min
7	Max

When looking at the decomposition of the number of violations in smaller chunks, you can see that the interest rates distribution is normal, and the cumulative distribution is somewhat linear. Because of the normal distribution of the number of violations, we can assume that further decomposing the number of violations uncertainty won't change the model's decision. The normal distribution would remain the same no matter how many assessments the number of violations was decomposed into.

Conclusion/Lessons Learned:

From this assignment, our team concluded that none of the added uncertainties change the model's decision, and the best treatment system is still the Lakeside Raptor SAP. Since all the added uncertainties are independent of the decision-making process, they don't change the decision because they all cause the same effects and changes to the expected value, no matter the treatment system used. Choosing the Lakeside Raptor SAP or the Enviro-Care Flo Beast doesn't change the likelihood of a certain interest rate. The lesson we learned from this assignment is that if you want to have uncertainty affecting your decision, it should depend on the decision. If the probabilities of each interest rate were to change based on the treatment system used, that could have potentially caused our decision to be changed. Another lesson learned is that when you don't have factual data and you must generate data subjectively, like what we had to do for the uncertainty probabilities and the cumulative distributions, most of the data will be normal. This is especially true if we don't have much information about the uncertainty because if we don't have a lot of information, it is safer to assume the distribution is normal.

Project Assignment 4

Assignment Assumptions

- A normal distribution will be used to examine the probability of a given labor quality to occur
- An exponential distribution will be used to the examine the probability of delays and the impact on the project timeline
- A binomial distribution was used to examine the probability of violations and the impact on project fines

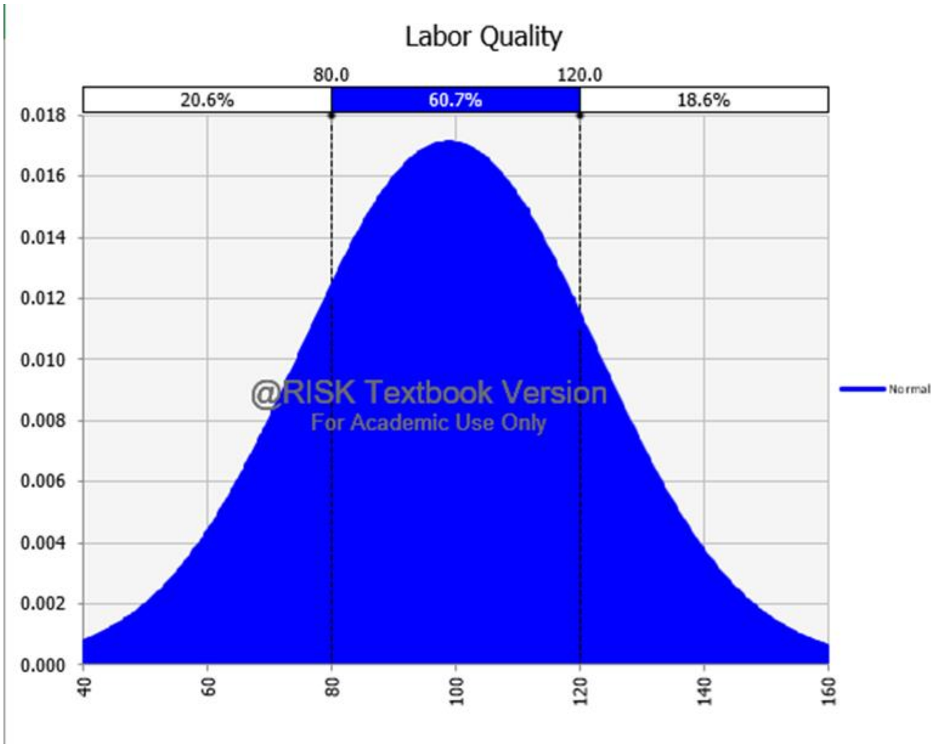
Assignment Response

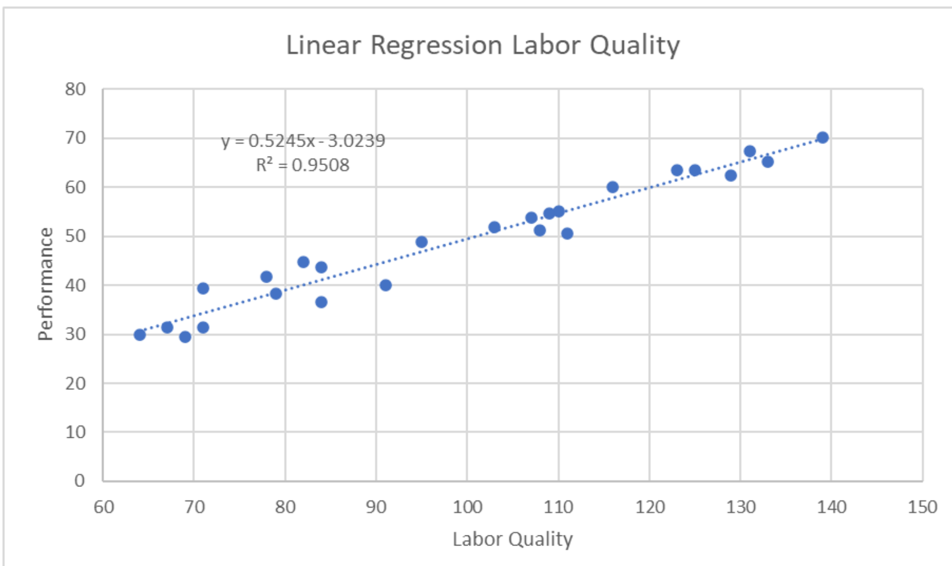
Normal Distribution

A normal distribution is appropriate for labor quality because the average labor quality is typically equivalent to what is expected for someone at that pay. Then workers can either overperform or underperform based on the standards set in previous projects. So, if the labor quality average is equivalent to meeting expectations at 100%, then the system's performance will stay constant with the parts and materials used, and labor will not increase or decrease performance. However, if labor quality is 85%, then there would be a 15% decrease in performance; if labor quality is 115%, then there would be a 15% increase in performance. We assume the average labor quality is around 100% of the employer's expectations. If it were not up to that amount, employees would be consistently fired, or pay would be decreased to fit the labor quality. Since the original document states that the standard pay is $40, we can assume that the standard labor quality meets that $40 rate.

Due to lack of information and the ability to rate labor quality in a single project. A dataset was generated for labor quality that fits a normal distribution. After implementing the normal distribution, the probabilities of the labor quality were adjusted to a three-set probability with the three labels being poor, mediocre, and great.

Labor Quality	Value	Probability
Poor	80%	0.206
Mediocre	100%	0.607
Good	120%	0.187





After incorporating the normal distribution into the influence diagram and decision tree, the decision remains the same. The best option continues to be the Lakeside Raptor SAP. However, incorporating the normal distribution reduces the expected value by around 8500, weakening the decision slightly. The next closest option is the Enviro-Care Flo Beast, with an expected value of 82,000 lower than the Lakeside Raptor SAP. Therefore, labor Quality does not hold a large significance in the overall decision-making process of this project.

Exponential Distribution

An exponential distribution is appropriate for delays as the more delays a project experiences the longer the construction time becomes as the first cause of delay typically needs to be addressed before the latest cause of delay is addressed.

As the observations are within this research's scope, it was done to find comparable data. After implementing the exponential distribution, the probabilities for delays were adjusted to a three-set probability with the three labels being ahead of time, on time, delayed. According to a study done by the Norwegian government the average project delay was approximately 10 months. Similarly, within the same study the Australian National Audit Office reprobated their government projects were delayed an average of 32 months. Therefore, given these expectations it can be assumed for this project that completion in 10-30 months is acceptable, anything with less than 10 months' delay is on time, and anything beyond 30 months is unacceptably delayed.

4.1. Descriptive statistics

Table 2. Delays in Norwegian government projects (months)

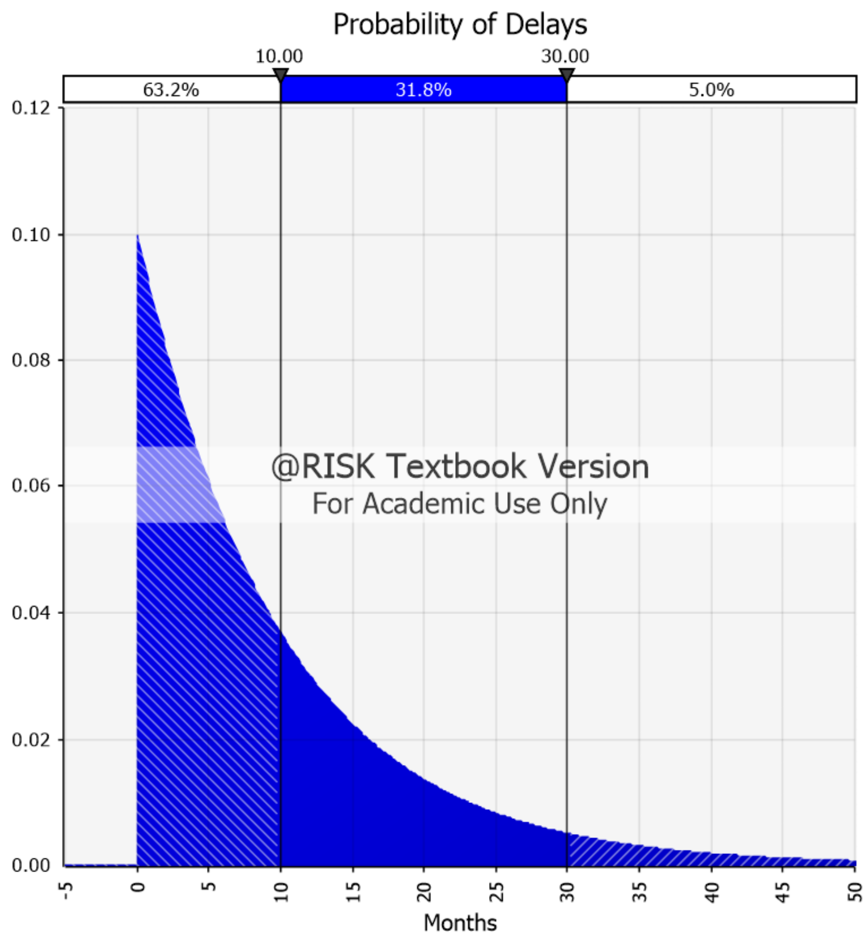
Sector	Roads	Railways	Buildings	Defence	ICT	Other	Total
N	65	9	15	17	5	1	112
Mean delay	4	8	3	30	40	32	10
Median	0	0	0	37	14	32	2
Standard deviation	9	13	7	33	48	-	21
Minimum value	-15	0	-8	-35	0	32	-35
Maximum value	47	36	22	97	105	32	105
Share of projects with delays	45%	45%	13%	88%	80%	100%	53%

Table 2 shows that the average delay in large Norwegian government projects is 10 months. There is a considerable right skew as the mean is much larger than the median delay that just 1.5 months. The results are very dispersed with a standard deviation of 21 months. The mode is 0, that is a typical government experience no delays. In fact, in our sample 42 projects or 38% are completed according to the agreed schedule.

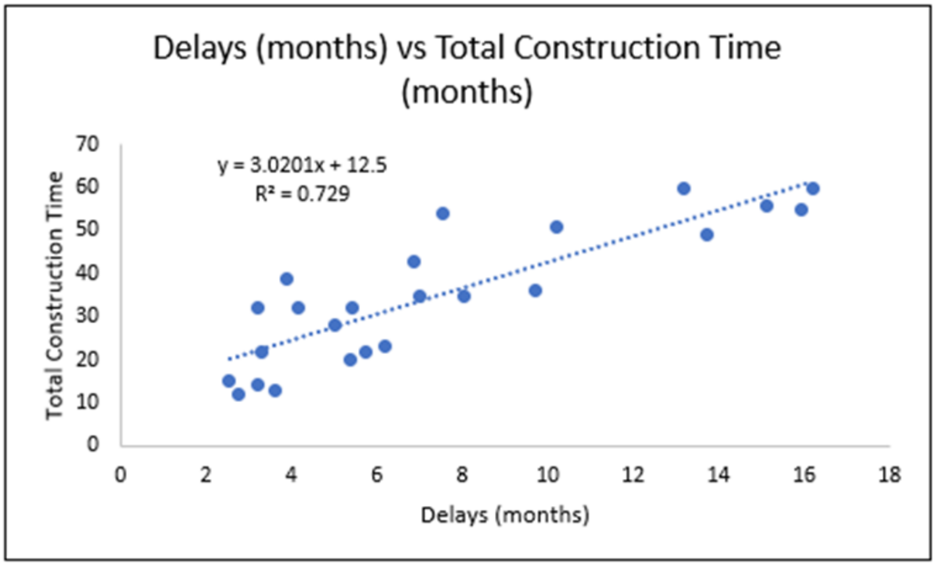
Figure 1: Norwegian Project Delays (https://www.sciencedirect.com/science/article/pii/S1877050921022985)

An exponential distribution was created given this information and the table developed below:

Months Delayed	Project Construction Time	Probability
Less than 10 months	On time	63.2%
Between 10-30 months	Acceptable Delays	31.8%
Greater Than 30 months	Unacceptable Delays	5.0%



According to Alice Technologies large projects typically take 20% longer to finish and 98% of projects become delayed at some point. Therefore, we can develop a data set that shows the number of months of delay vs the total project time in months to anticipate the impact of delays on our project where the delays compose about 20% of the total project time. Therefore, a major assumption is that delays will occur no matter what and that analysis of the impact of delay sis more valuable than believing delays won't occur.



After incorporating the exponential distribution of the probability of delays into the influence diagram and decision tree the decision remains the same. The best option remains the Lakeside Raptor SAP as there is a 63.2% probability that the project will proceed with less than 10 months of delay and be on time. Incorporating the exponential distribution probabilities into the influence diagram reduced the expected value by about 7300 weakening the decision. Therefore, it can be said when applying this model delays are likely to occur, but as we've defined them don't significantly impact the project.

Binomial Distribution

According to the U.S. Bureau of Labor Statistics, the total non-fatal work injury and illness rate is 2.7-2.8 per 100 full-time workers over the past 5 years. The team deduced that the distribution of these values relates to the probability of the number of labor violations at the wastewater treatment plant. The team deduced that if the probability of a violation would be a binomial distribution of the probability of a violation per 100 labor hours per worker is 2.8%. The team extrapolated that the chance of the plant having a OSHA violation is 2.8% per employee over the course of construction.

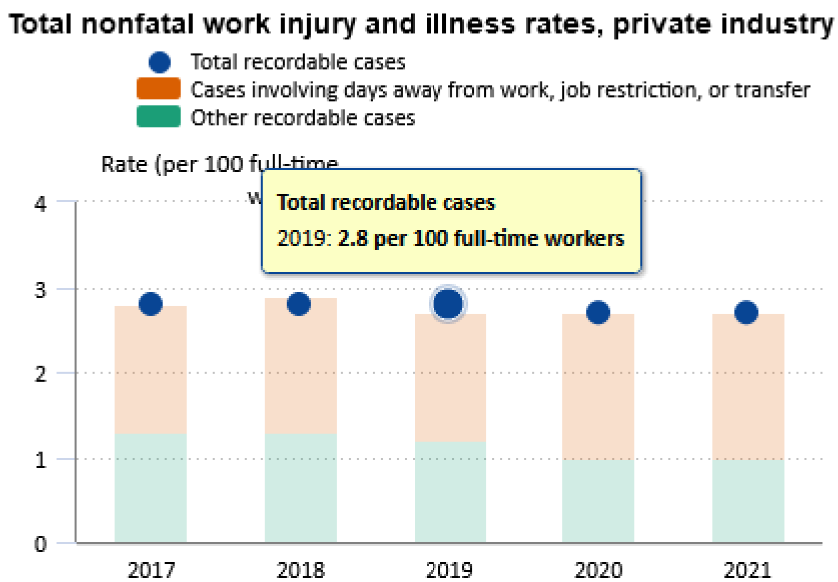
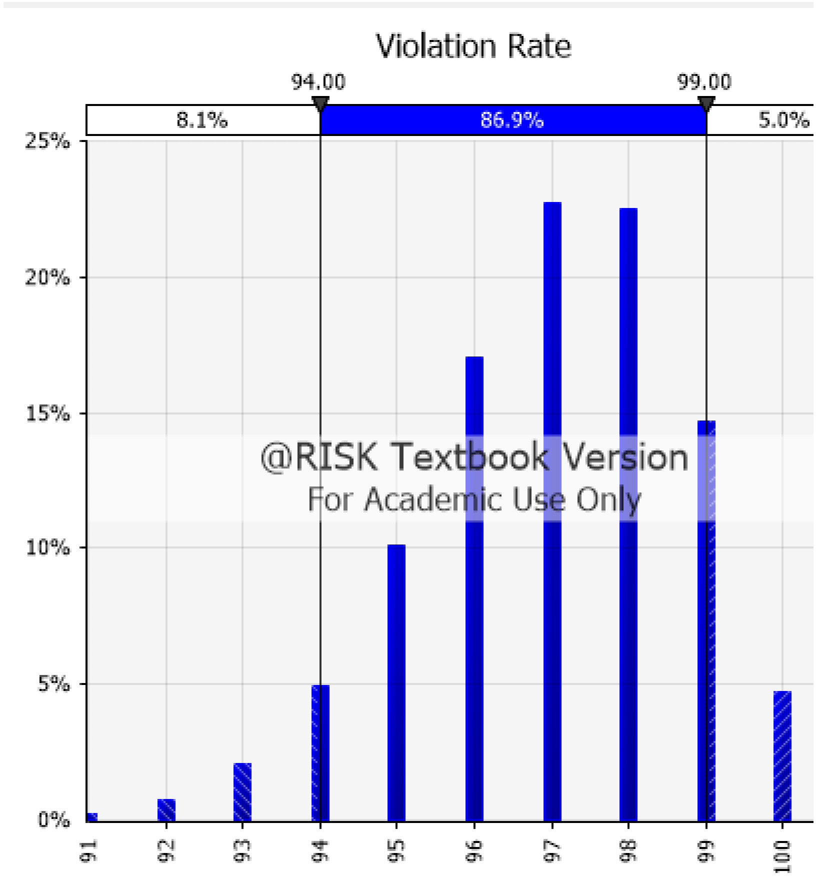


Figure 1: U.S. Bureau of Labor Statistics (https://www.bls.gov/iif/)

Due to the lack of publicly available datasets of OSHA rates for a wastewater facility, a dataset was generated for violation rate that fits a binomial distribution. The values were categorized into 3 categories to match the violation rate. An assumption was made that the federal statistics translates to the violation rate per week for a facility that has a work force of 100 trained workers or fewer. This assumption also allowed the facility to capture any violations internally before state or federal inspectors marked these violations as repetitions.

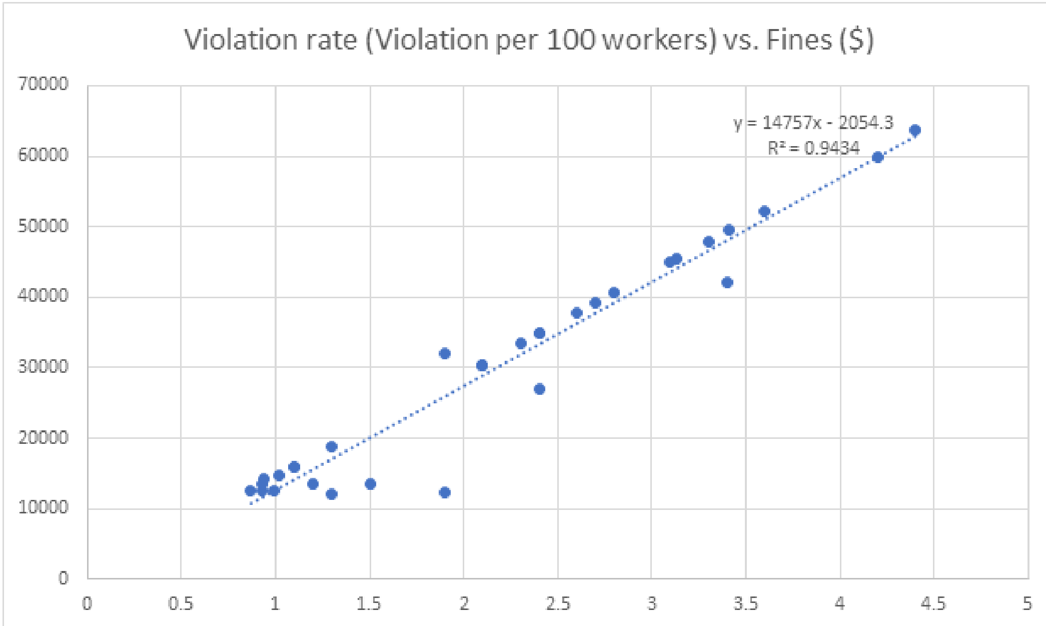
OSHA-safe	Value	Probability
Dangerous	> 5% violations per week	0.025
Serious	> 3% violations per week	0.298
Concerned	1-3% violations per week	0.273
Good	0-1% violations per week	0.404

These violation categories matched the number of violations that were originally modeled into the influence diagram. Each violation category is matched to the number of fines (0-4) given by state and federal OSHA regulators.



Linear Regression of Binomial Probability of Violations

According to the U.S. Bureau of Labor Statistics, the Occupational Safety Hazard Administration's (OSHA) violation fines have an average rate of $14,502 per violation that exceeds safety requirements. The user-generated data as graphically represented below show a high correlation between a facility's violation rate and the expected monetary penalty against OSHA regulations.



Incorporating the binomial distribution into the influence diagram and decision tree, the decision remained the same. The best option is the Lakeside Raptor SAP as it had the highest expected values in our model with the highest probability to succeed without incurring large fines for failing OSHA regulations. Using binomial distribution probabilities, the expected values increased because the probability favored the likelihood that all 3 design options would incur fewer than 2 violations. Our original model skewed towards 2-3 violations as it was normally distributed.

Project Assignment 5

Assignment Assumptions

Identifying three major decisions of our wastewater treatment design choices required the identification of the decision maker. The team assigned that a certified project manager would be making the key decisions in the financial management, safety and allocation of capital investments with a team of department advisors. The three decisions from a project manager's perspective would be the identifying the uncertainty found in allocating a budget for the initial capital investment, which naturally would attract various firms to commit to good proposals for the project manager's Request for Proposals (RFPs). The budgets allocated for each plant design from maintaining the status quo, replacing the entire treatment facility, and upgrading the automation of the current facility design can dictate their competitive efforts to win the bid.

The second decision that involved uncertainty that could greatly benefit from utility functions was setting the average hourly wage of technicians and other workers for the design. Identifying the probability of allocating budgets for competitive wages that could dictate the efficiency of the plant and the technical proficiency the employees. The third decision was the budget allocation of safety equipment to meet the requirements of the federal, state and local regulations for safety, including OSHA regulations.

The assumptions around these utility functions are that the facility is located within a financially conservative municipality that increases the probability of smaller budgets. Despite the identified cost of the facility upgrade and the possible replacement of the entire facility, the probability of lower wages, lower investments in safety and smaller budgets for RFPs skew towards higher values. These values can be found in the decision trees defined below. Furthermore, these probabilities were discussed and unanimously agreed upon by representatives of the management team, employees, and the district financial manager.

Assignment Response

Certain equivalents and probabilities were used to build each utility function for the three variables: wages, capital investment and safety. There were no differences between the utility functions as it was assumed that constant risk aversion was present for the calculation of certain equivalents. It is assumed that the management team and the district financial manager are risk-averse in order to maintain a conservative budget for meeting the wastewater treatment needs of the local county and surrounding agricultural economies. The exponential distribution was used to model both risk seeking and risk averse utility functions using PrecisionTree modeling for each of the three functions.

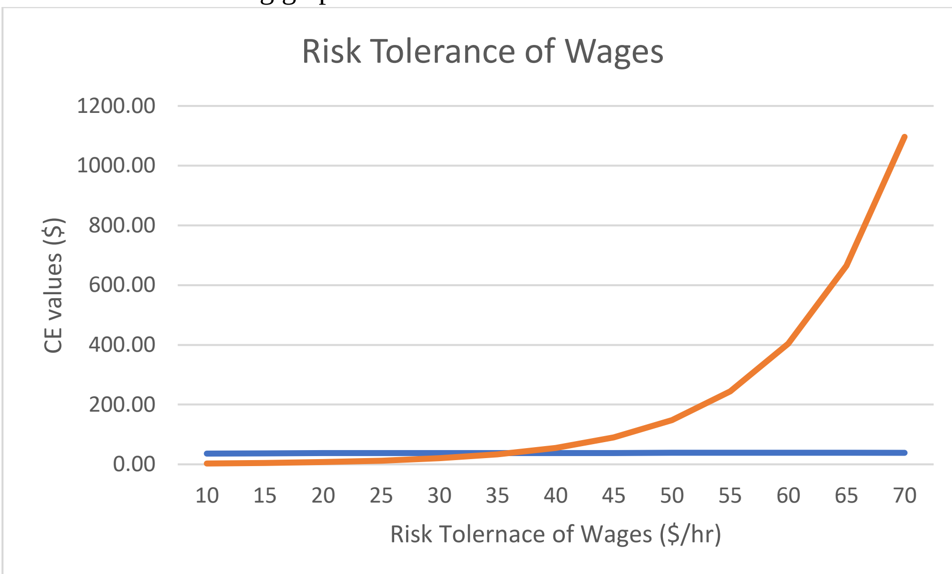
1. Wages

    a. Table used for risk tolerances

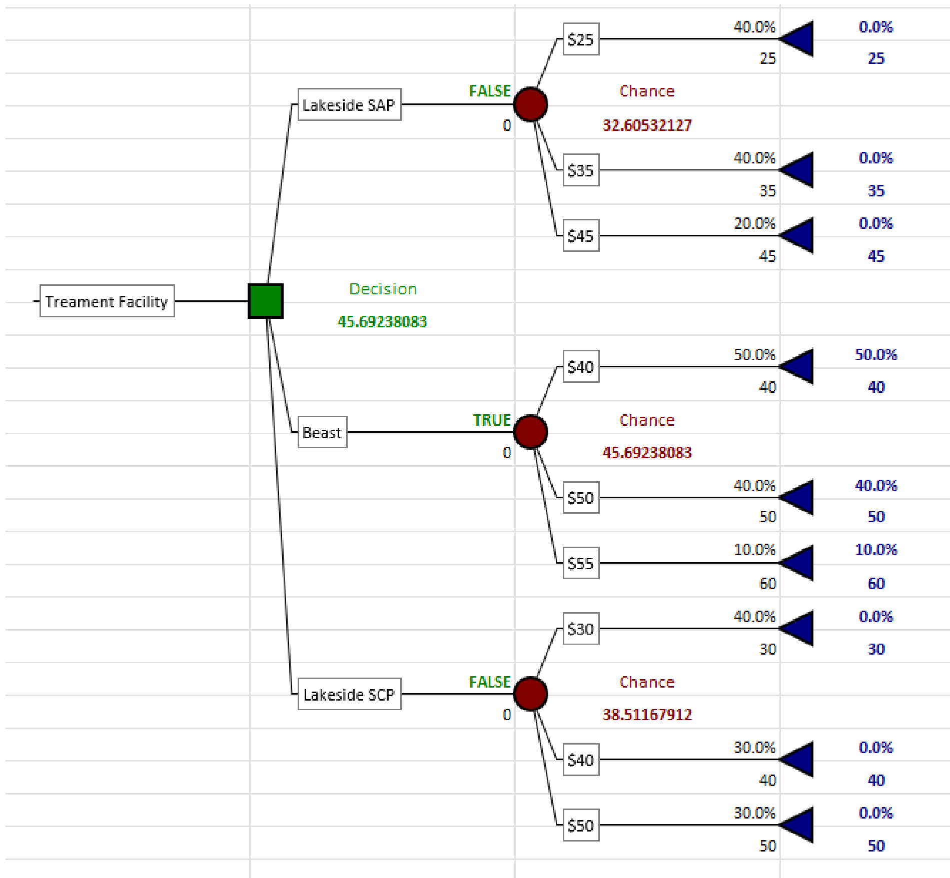
Risk Tolerance	**Risk Averse**	**Risk Seeking**
	CE	CE
10	35.96	2.72
15	36.86	4.48
20	37.35	7.39
25	37.67	12.18
30	37.88	20.09

35	38.04	33.12
40	38.15	54.60
45	38.25	90.02
50	38.32	148.41
55	38.38	244.69
60	38.43	403.43
65	38.47	665.14
70	38.51	1096.63

b. Risk Aversion/Seeking graph



c. Decision Tree with probabilities and assigned budget for hourly wages:

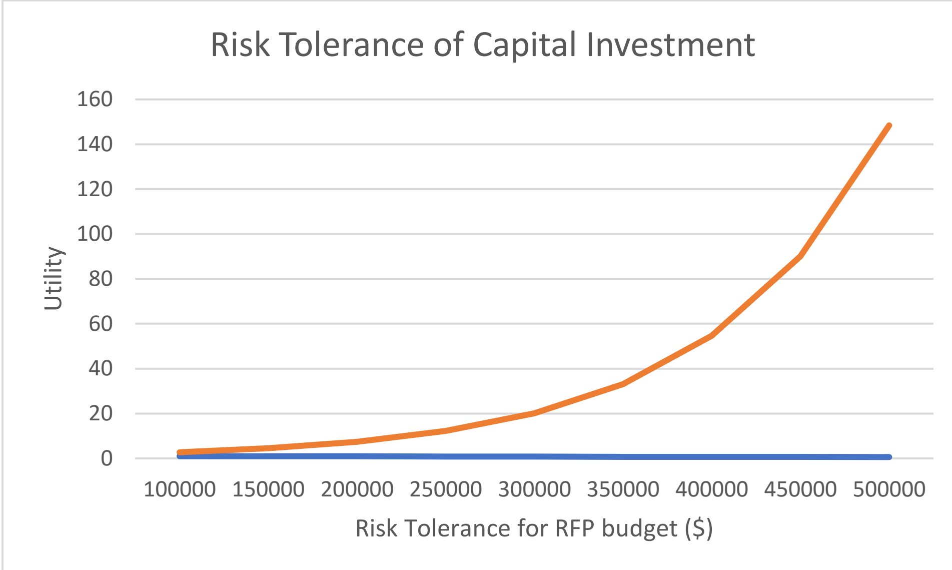


2. Capital Investment

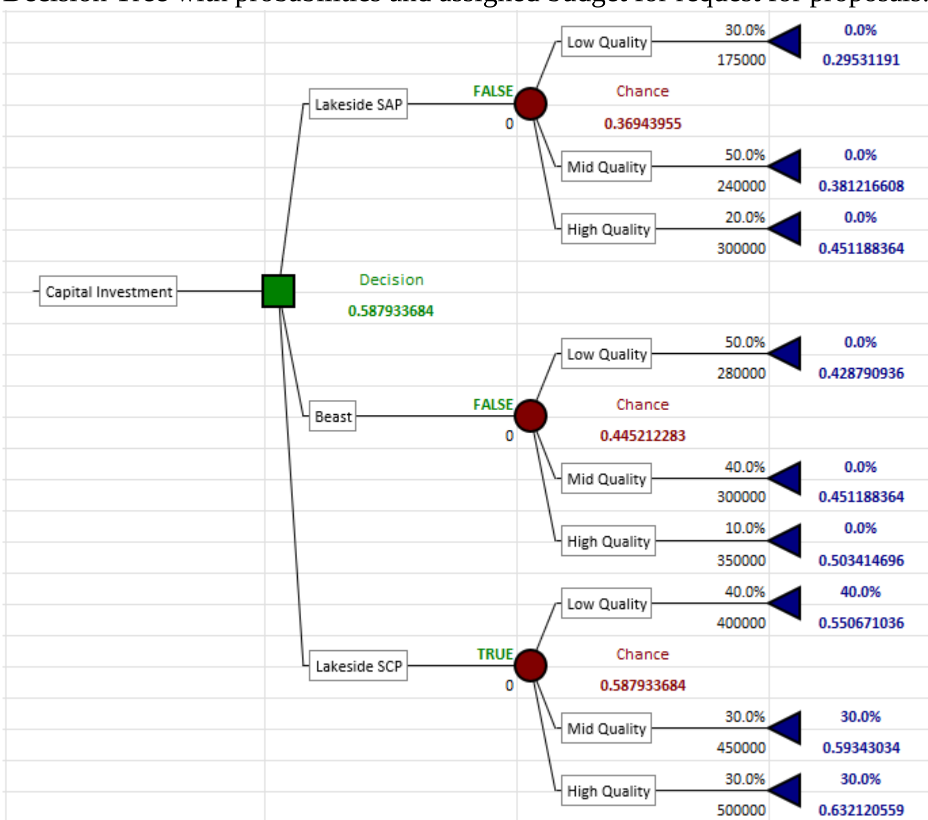
a. Table

Risk Tolerance	**Risk Averse**	**Risk Seeking**
	(EU)	
100000	0.98731966	2.72
150000	0.9465683	4.48
200000	0.89	7.39
250000	0.83	12.18
300000	0.77	20.09
350000	0.72	33.12
400000	0.67	54.60
450000	0.63	90.02
500000	0.59	148.41

b. Risk Aversion/Seeking graph



c. Decision Tree with probabilities and assigned budget for request for proposals:

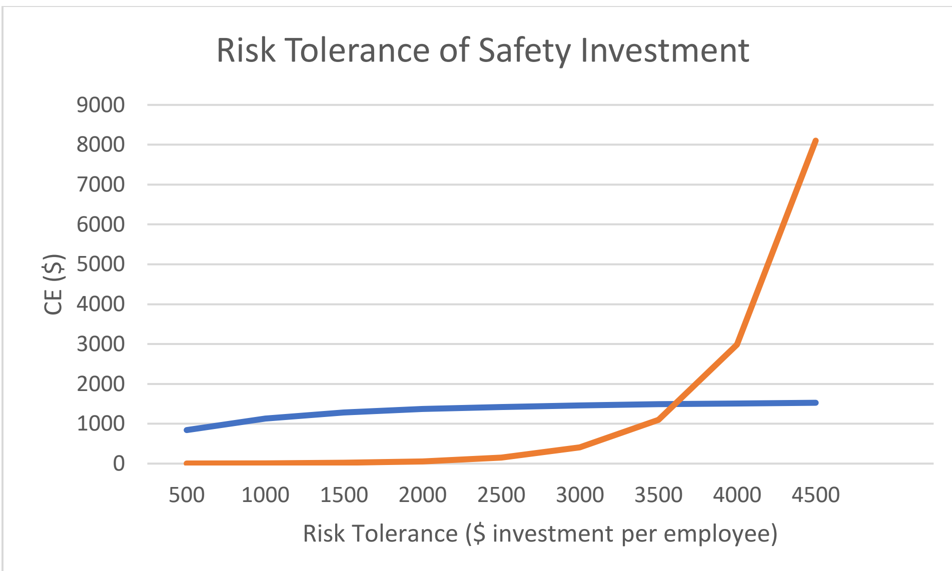


3. Safety

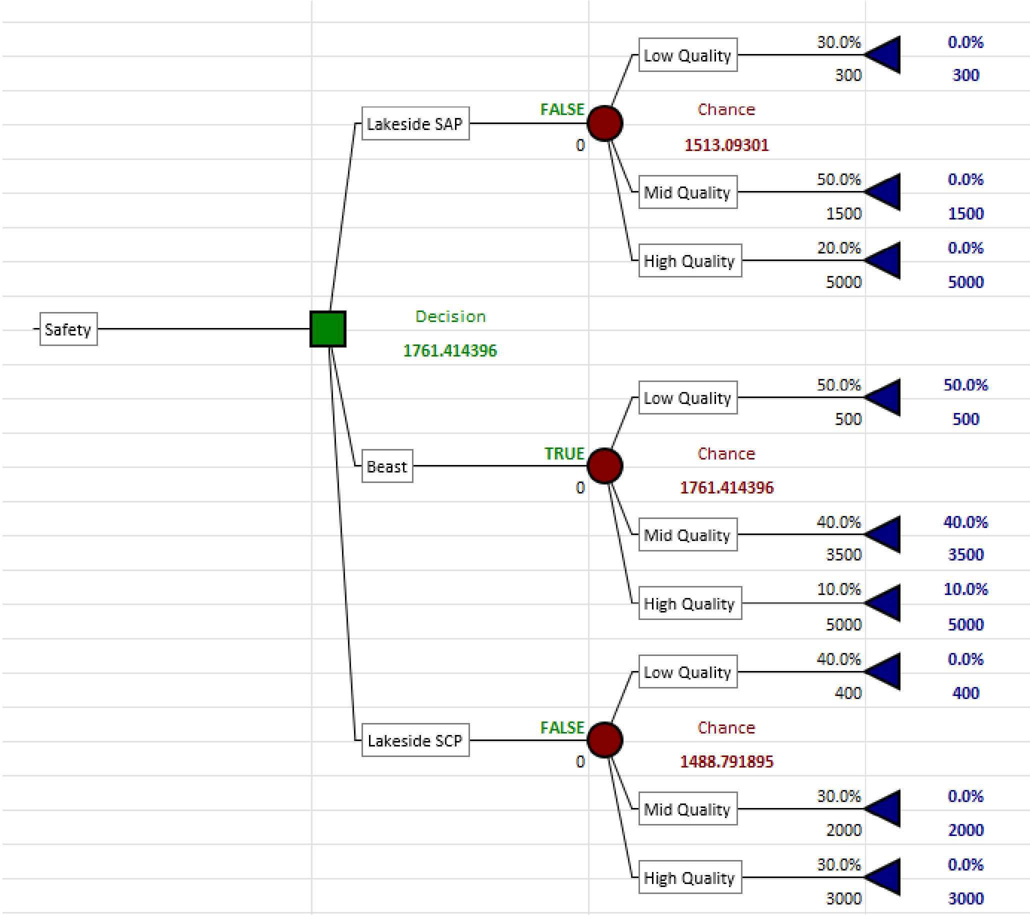
a. Table

Risk Tolerance	Risk Averse	Risk Seeking
	CE	CE
500	841.0852152	2.72
1000	1128.047102	7.39
1500	1279.794115	20.09
2000	1367.21	54.60
2500	1422.84	148.41
3000	1461.04	403.43
3500	1488.79	1096.63
4000	1509.82	2980.96
4500	1526.29	8103.08

b. Risk Aversion/Seeking graph



c. Decision Tree with probabilities and assigned monetary funds for safety equipment



Conclusions/Lessons Learned

Through the analysis with utility functions, it was a more refined process to determine the best course of action to choose a wastewater facility design regarding each variable. Unfortunately, the values favored higher payout values due to the lack of additive utility functions. For example, the replacement design (Beast) was favored in safety because it had a higher probability for a larger investment in the budget of safety equipment. With the exponential distribution function enabled for the utility analysis of the model, it was difficult to determine the best design choice because the values were not weighted against other variables, such as lifecycle costs. In addition, not all stakeholder requirements were used to weigh a normalized score. It would be helpful to analyze the cost of training current and future workers and incorporate those costs into the budget for hourly wages of all employees. The three models skew towards higher utility values, which maximize the likelihood of the costs of the design facility.

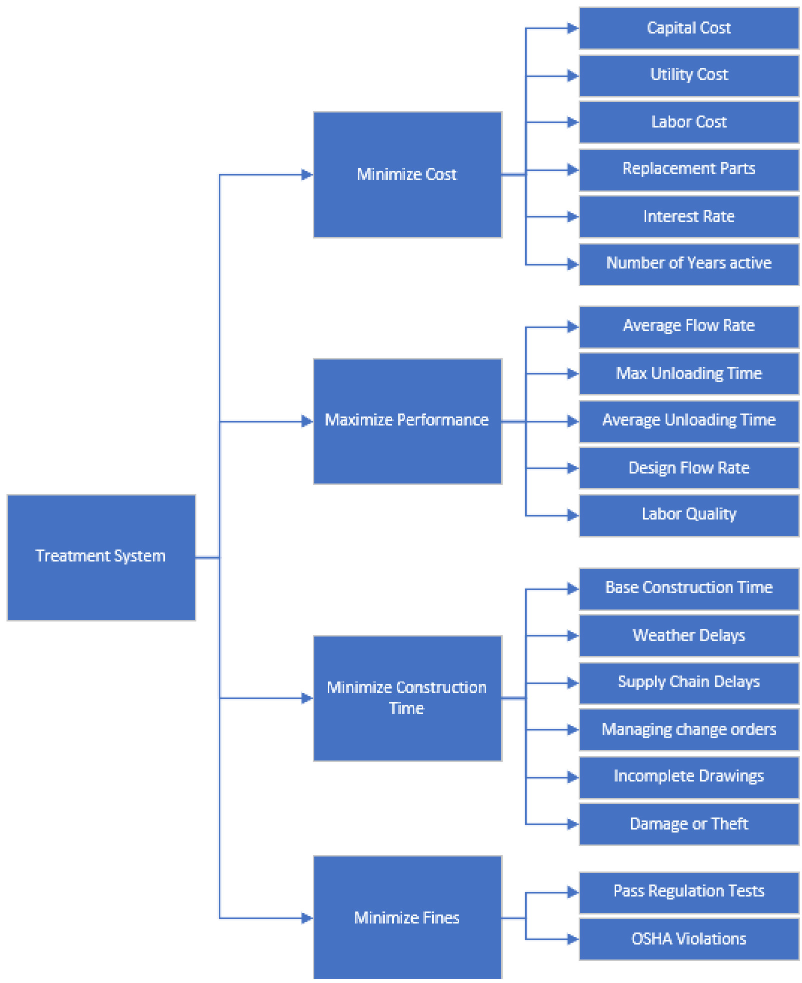
Project Assignment 6

<u>Assignment Assumptions</u>

- The several types of delays will all be split into different attributes of construction time.
- The likelihood of passing regulatory tests will be used as the score for passing initial scores.
- Delay scores are based on the number of months annually
- Delay scores a made subjectively based on information found on google about construction delays.
- Cost and Performance scores are taken from the *Septage receiving Facility Upgrade Preliminary Engineering Report* developed for the Upper Occoquan Service Authority in Centreville, Virginia.
- Swing weights will be used to develop scores.
- The treatment system with the highest overall score is the best option according to the utility functions.

Assignment Response

Treatment System Objectives Hierarchy



Objective and Attribute Utility Functions and Weights

Objectives	Attributes	Ranking	Obj Rating	Attribute Rating	Obj Weight	Attribute Weight
Minimize Cost		1	100		0.46511628	
	Capital Cost	1		100		0.303030303
	Utility Cost	6		20		0.060606061
	Labor Cost	3		55		0.166666667
	Replacement Parts	5		30		0.090909091
	Interest Rate	4		50		0.151515152
	Number of Years Active	2		75		0.227272727
			Total	330		1
Maximize Performance		2	70		0.3255814	
	Average Flow Rate	1		100		0.266666667
	Max Unloading Time	2		90		0.24
	Average Unloading Time	4		60		0.16
	Desing Flow Rate	5		40		0.106666667
	Labor Quality	3		85		0.226666667
			Total	375		1
Minimize Construction Cost		3	30		0.13953488	
	Base Construction Time	1		100		0.277777778
	Weather Delays	3		65		0.180555556
	Supply Chain Delays	2		70		0.194444444
	Managing change orders	4		50		0.138888889
	Incomplete drawings	5		45		0.125
	Damage or Theft	6		30		0.083333333
			Total	360		1
Minimize Fines		4	15		0.06976744	
	Pass Regulation Tests	1		100		0.571428571
	OSHA Violations	2		75		0.428571429
			Total	175		1
		Total	215		1	

Treatment System Values

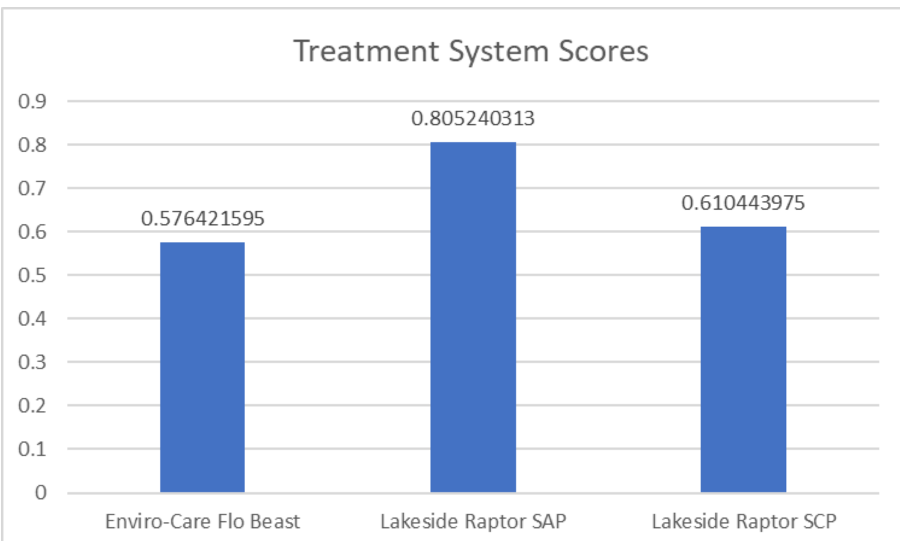
	Enviro-Care Flo Beast	Lakeside Raptor SAP	Lakeside Raptor SCP
Capital Cost	$300,000	$240,000	$470,000
Utility Cost	$8,000	$8,000	$16,000
Labor Cost	$4,000	$3,500	$4,000
Replacement Parts	$1,984	$992	$3,500
Interest Rate	0.06	0.06	0.06
Number of Years Active	20	20	20
Average Flow Rate	346	402	420
Max Unloading Time	29	19	17
Average Unloading Time	10.3	7.6	7
Desing Flow Rate	650 gpm @ 4% solids	400 gpm @ 3% solids	400 gpm @ 3% solids
Labor Quality	Medicore	Medicore	Medicore
Base Construction Time	18	24	30
Weather Delays	1	1	1
Supply Chain Delays	1.7	2.3	2.5
Managing change orders	0.3	0.4	0.2
Incomplete drawings	0.7	1	0.6
Damage or Theft	1	0.75	0.75
Pass Regulation Tests	0.85	0.8	0.9
OSHA Violations	4	3	3

Treatment System Attribute Scores

	Enviro-Care Flo Beast	Lakeside Raptor SAP	Lakeside Raptor SCP
Capital Cost	0.739130435	1	0
Utility Cost	1	1	0
Labor Cost	0	1	0
Replacement Parts	0.60446571	1	0
Interest Rate	1	1	1
Number of Years Active	1	1	1
Average Flow Rate	0	0.756756757	1
Max Unloading Time	0	0.833333333	1
Average Unloading Time	0	0.818181818	1
Desing Flow Rate	1	0	0
Labor Quality	1	1	1
Base Construction Time	1	0.5	0
Weather Delays	1	1	1
Supply Chain Delays	1	0.25	0
Managing change orders	0.5	0	1
Incomplete drawings	0.75	0	1
Damage or Theft	0	1	1
Pass Regulation Tests	0.5	0	1
OSHA Violations	0	1	1

Treatment System Final Scores

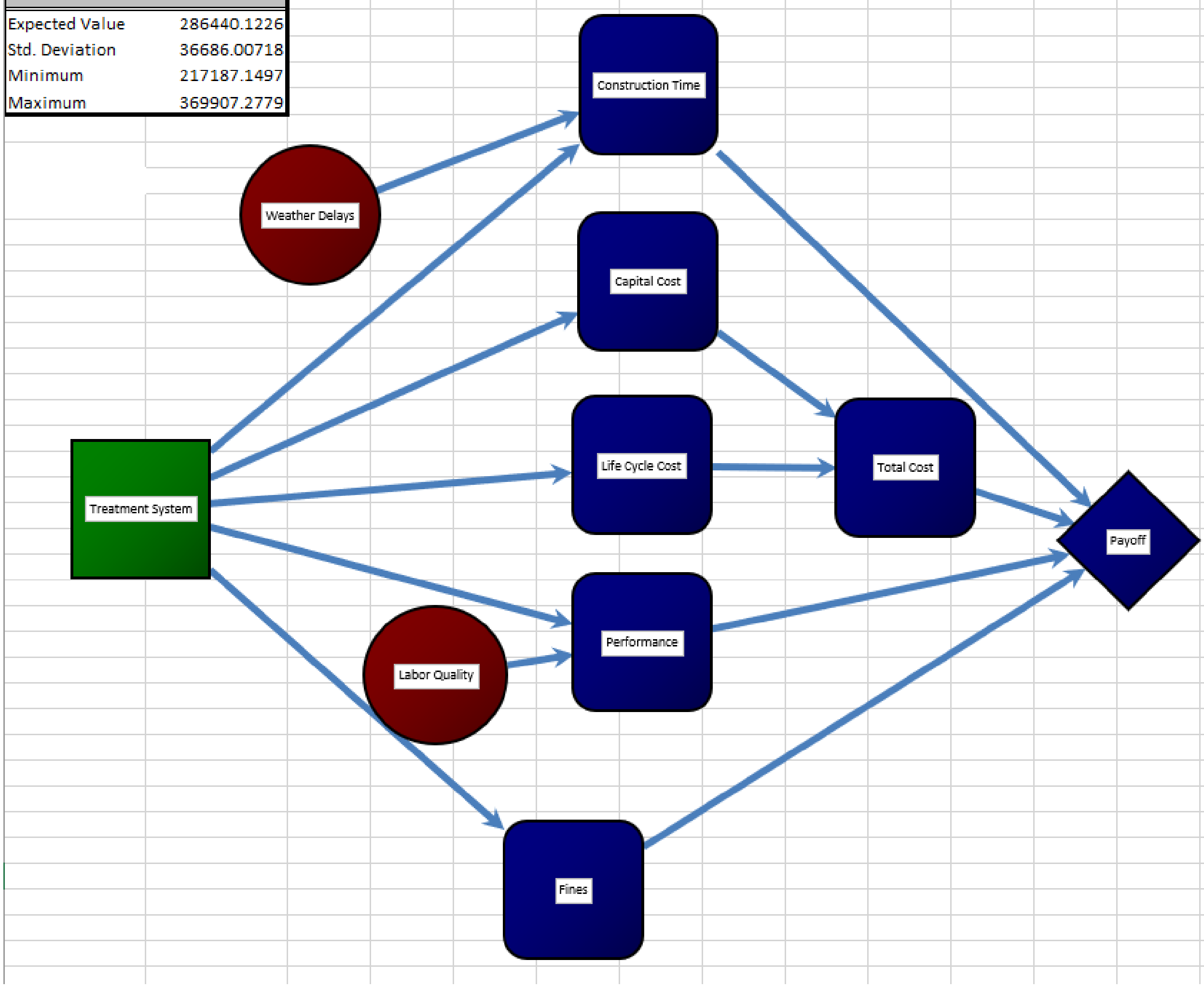
Objectivies	Enviro-Care Flo Beast	Lakeside Raptor SAP	Lakeside Raptor SCP
Minimize Cost	0.718324287	1	0.378787879
Maximize Performance	0.333333333	0.759377559	0.893333333
Minimize Construction Cost	0.815972222	0.451388889	0.527777778
Minimize Fines	0.285714286	0.428571429	1
Total Score	0.576421595	0.805240313	0.610443975



Our recommendation using the updated objective hierarchy and utility functions developed using swing weights is consistent with our initial decision as well as our decision in the rest of the assignments. The best overall treatments system is the Lakeside Raptor SAP, and this system should be the system implemented. Even though some of the scores are created subjectively and without a lot of data, we are still confident in our decision because of our consistent results throughout the entire project as well as the large score difference between the three options. The main reason Lakeside Raptor SAP outscored the other two options by the large margin is because cost in the most influential and dominant objective in the objective's hierarchy. This decision was made because of the information provided in the report we use as our source. When reading the initial report, it is clear to see that the stakeholders most important objective is to minimize cost.

Influence Diagram

Diagram Less Variables (2) (2)	
Expected Value	286440.1226
Std. Deviation	36686.00718
Minimum	217187.1497
Maximum	369907.2779

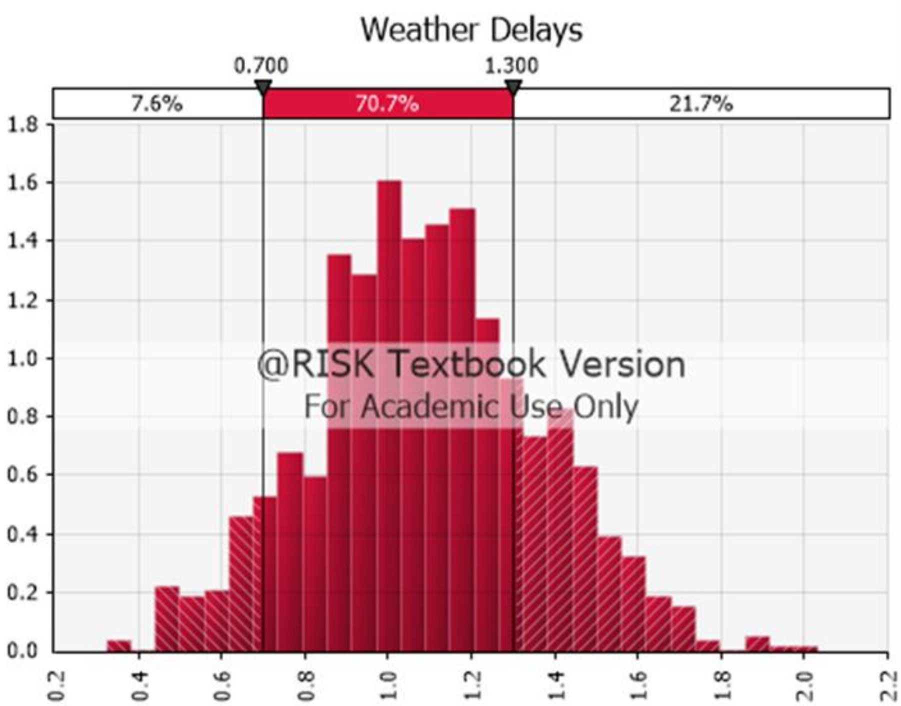


The two stochastic variables identified in this decision are the weather delays and the labor quality.

Simulation

Weather Delays

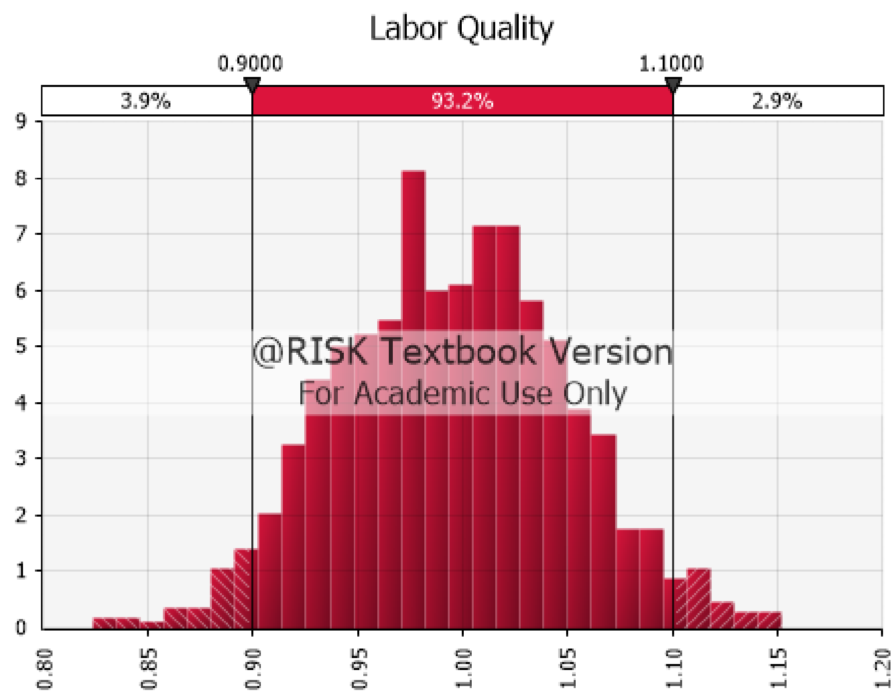
Weather Delays					
Year		Low	Most Likel	High	Value
1		0.5	1.05	1.65	1.071468
2		0.4	1	2	1.171935
3		0.6	0.95	1.5	1.035946
				Avg	1.093116



Statistics	
	Avg / Value
Cell	Sheet2!G6
Minimum	0.3232
Maximum	2.0333
Mean	1.0931
90% CI	± 0.0141
Mode	1.1241
Median	1.0869
Std Dev	0.2712
Skewness	0.0929
Kurtosis	2.9268
Values	1000
Errors	0
Filtered	0
Left X	0.700
Left P	7.6%
Right X	1.300
Right P	78.3%

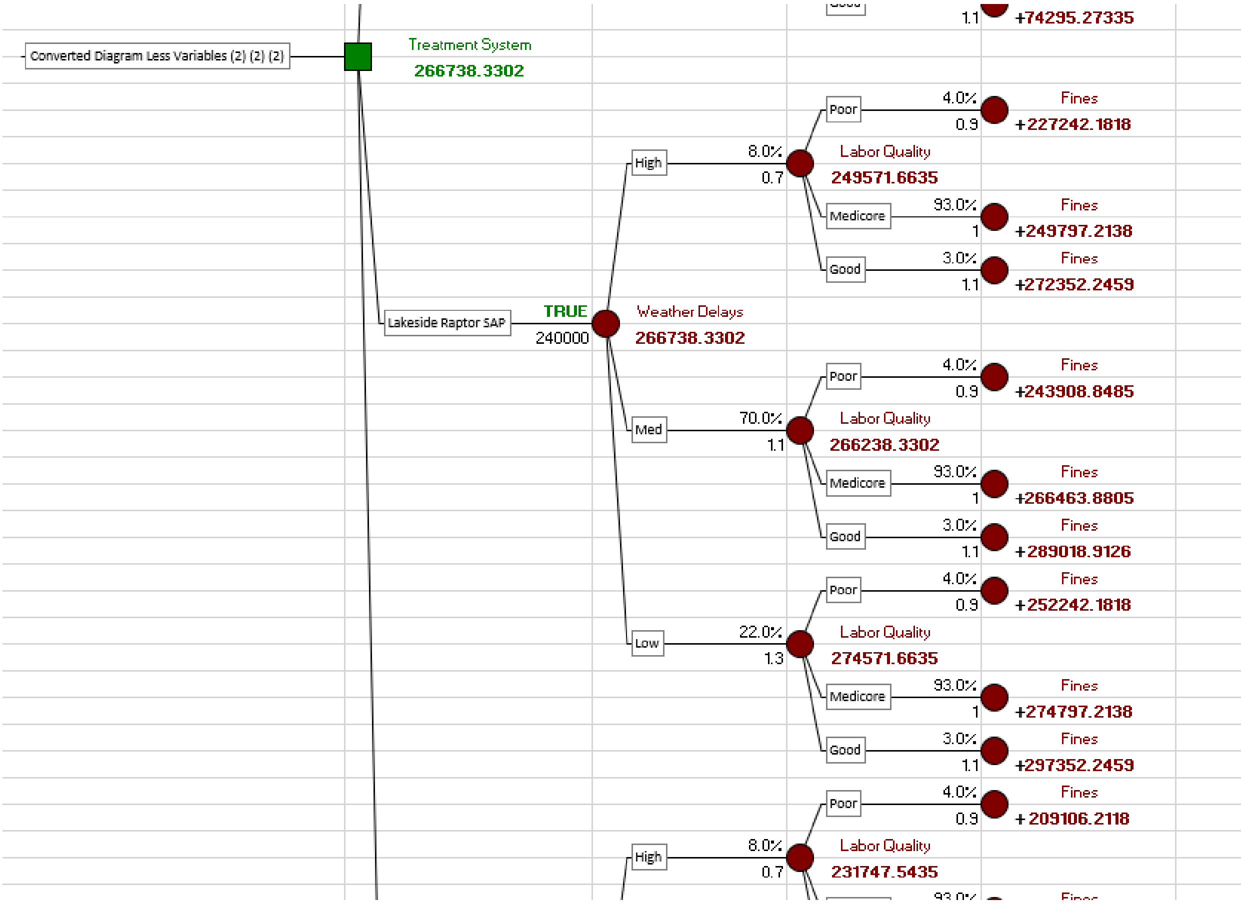
Labor Quality

Labor Quality					
Year		Low	Most Likel	High	Value
2		0.8	1.05	1.2	1.007016
4		0.9	1	1.2	1.043025
6		0.7	1	1.25	0.97853
8		0.6	1	1.1	0.870211
10		0.8	0.95	1.25	1.014537
12		0.85	1.1	1.3	1.078528
14		0.9	1.2	1.45	1.17853
16		0.65	0.9	1.15	0.9
18		0.75	0.9	1.1	0.921475
20		0.7	1	1.2	0.957035
				Avg	0.994889



Statistics	Avg / Value
Cell	Sheet2!G28
Minimum	0.82325
Maximum	1.15223
Mean	0.99489
90% CI	± 0.00284
Mode	0.97897
Median	0.99475
Std Dev	0.05446
Skewness	-0.0019
Kurtosis	2.8115
Values	1000
Errors	0
Filtered	0
Left X	0.9000
Left P	3.9%
Right X	1.1000
Right P	97.1%

Decision Tree



When implementing the simulation results of weather delays and labor quality into a decision tree to make our decision. The final decision remains the same from the utility functions. The best option for a treatment system is the Lakeside Raptor SAP. I'm confident in the result because it is the same decision from our utility functions and the previous assignments. Even though the difference between Lakeside Raptor SAP and Lakeside Raptor SCP is only about 15,000, the consistence between the utility functions, the influence diagram without the simulated variables and the decision tree with the simulated variables leads our team to believe that the SAP system is the best decision.

Conclusions/Lessons Learned

In conclusion, for assignment 6, the updated objectives hierarchy with the utility functions, the influence diagram, and the decision tree with simulation implementation all point to our decision's best treatment system, the Lakeside Raptor SAP. The decision is much closer this time, with only a 5% difference in expected value between the best option and the second-best option, the Lakeside Raptor SCP. The lessons learned from this assignment are that making a well-defined objective hierarchy is very important. Repeating the objective hierarchy made our team realize there are some other attributes we didn't account for, for each of our objectives. The new attributes could have changed our decision, but our decision didn't change in this circumstance.

Another thing our team learned was that simulations are very useful when making a decision that involves an extended period of time. For example, our original design only had the performance objective as a whole. Still, we decided to simulate work quality every two years in an attempt to define a good distribution that would represent the average labor quality for the entire treatment facility operation period. This new distribution improved our team's understanding of how labor quality would change over time.

Summary of Conclusions/Recommendations and Lessons Learned

After completing all the assignments, our team can conclude that the best option for the wastewater treatment facility is the **Lakeside Raptor SAP** system. Throughout each assignment, the Lakeside Raptor SAP was the best option. From our initial draft of the influence diagram and the decision tree in project assignments one and two to project assignment six with the updated objective hierarchy with utility functions and simulations, the best decision each time was the Lakeside Raptor SAP. In some instances, the differences in expected value were a lot closer, like project assignment six, where the difference was only about 5%, and there were other instances where the difference was closer to 17%, like project assignment two, three, and four. Our team is confident in our decision because of the consistency in our results. The initial analysis conducted for this decision yielded the same results as ours. The initial analysis focused solely on cost, while ours concentrated on cost, performance, construction time, and regulations; the results are still the same. But because the initial analysis focused solely on cost, 50% of our decision-making was based on cost, and the other 50% was based on the other three objectives.

Some of the lessons we learned throughout this project are that most decisions made are made with some subjective results or subjective assumptions made during the process. Finding relevant data for every aspect of your decision is difficult. When there isn't any data, you need to be able to make assumptions about your project that give you the ability to make your decision. It is also essential to state these assumptions because if the user finds one of the assumptions to be incorrect, they should be able to fix that mistake and adjust the results. Another lesson learned when completing this project is that it is vital to obtain as much information from a direct source as possible. Collecting information or creating a relationship with a company or organization you are making a recommendation to is very important. Obtaining an objective hierarchy from them is an essential first step. You can see from the differences in our expected values from assignment one to six that changing your objective hierarchy can change your decision drastically, even though it didn't change our decision in this project. A fundamental understanding of your objective is the key factor in making any decision. It shouldn't be skipped or left incomplete in order to get to the computational part of the decision.