Case 4 - Oakville Hydro

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Oakville Hydro has a choice of buying one of the following engine from GE Jenbacher

Engine	Rated Output (kWe)	Engine Intake Requirement (m^3/day)	Expected Capital Cost
J316	847	8,755	$2,000,000
J320	1,059	10,946	$2,500,000
J416	1,426	14,740	$2,900,000

They can also choose to integrate a storage tank into the engine. The storage tank can store 1,855 m^3 of digester gas.

Costs

Capital cost depends on engine type, at $2M, $2.5M, $2.9M respectively

Installation cost of the engine is $32,000

Annual maintenance and unforeseen downtime is 7% of **total** capital costs

The capital cost of integrating the storage tank is $50,000

Revenues

1 kWh is sold at $0.1985/hour at peak hour

1 kWh is sold at $0.1336/hour at off-peak hours

2,080 peak hours and 6,680 off-peak hours annually

Other data

Project life span is 20 years for all engine types

Discount rate is 9% annually

Oakville Hydro Project Details:

An engine + tank combination that offers the most favourable return in Present Value

The Present Value of the project should be positive

A minimum engine availability of 70% annually (365 x 70% = 256 days)

The engine only operates on the day when the daily engine flow requirement is met, or, if storage tank is integrated, when the sum of gas in tank and gas from flow exceeds the daily engine flow requirement

The storage tank never exceeds 1,855 m^3. If daily flow > requirement, excess flow goes into storage tank; if (daily flow + tank storage) > requirement, tank loses (requirement-flow) amount of gas to start engine; if (daily flow + tank storage) < requirement, engine would not start and gas flows into storage tank

Assumptions

We assume that the storage tank is full at the start of each year

We are using discrete distribution to model the daily gas flow data so the mean is chosen to represent each data range. For example, for the range 0 to 500 m^3/day, we use 250 m^3/day

We assume 365 days in each year

Every kWe of electricity output is purchased by consumer at the correct time period (peak or off-peak hours)

All qualitative requirements are met by each eligible engine

Model development - Distribution

First, we need to find the right distribution of the daily gas flow data

The data points don't fit any continuous distribution

So we use discrete distribution to develop the model

Total hours = 8784 hrs, frequency = hours/8784

"Distribution" = Discrete distribution (flow, frequency)

Using @Risk, randomize 365 data points from "Distribution"

Generate a total of 100 data sets (36,500 points in total)

Save these data points in "test.txt"

Flow	Hours	Frequency
250	80	0.009107468
750	174	0.019808743
1250	49	0.005578324
1750	46	0.005236794
2250	48	0.005464481
2750	64	0.007285974
3250	81	0.009221311
3750	95	0.010815118
4250	86	0.009790528
4750	90	0.010245902
5250	116	0.013205829
5750	101	0.011498179
6250	124	0.014116576
6750	146	0.016621129
7250	209	0.02379326
7750	169	0.019239526

Model development - Input Data

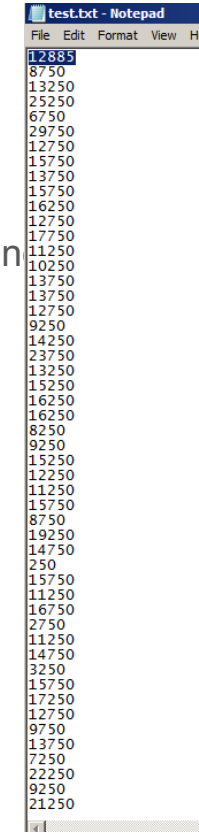
Then, use Java to find the availability of each engine + tank combination

Java reads the first line of “test.txt” file, which is minimum engine intake, and the next 36,500 lin
representing the data points generated from @RISK

The first line in “test.txt” file also tells Java if the project includes a tank

	J316	J320	J420
No Tank	8,755	10,946	14,740
Tank	6,900	9,091	12,885

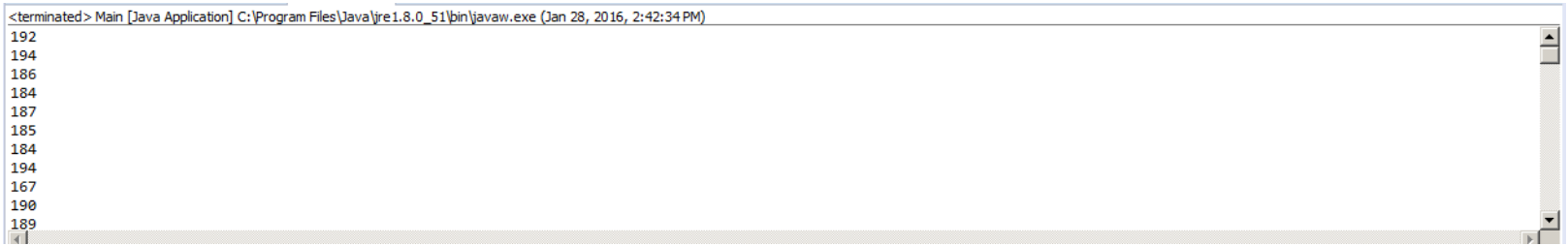
Java monitors the tank storage change after each day



Model development - Output Data

Then, for every 365 data points, Java counts the number of data points that has value > engine intake or value+tank storage>engine intake when tank is installed; the results are stored in an integer array of length 100

Each output represents the number of days in a year that the engine is available; there are 100 outputs



Model development - Java Code

```
import java.io.*;

public class Main {
    public static void main (String[] args) throws IOException{
        String line;
        int sum = 0;
        int m=1;
        int n=0;
        int [] data =new int[100];
        BufferedReader fin = new BufferedReader(new FileReader("test.txt"));
        line=fin.readLine();
        int req = Integer.parseInt(line);
        if (req==8755 || req==10946 || req==14740)
        {
            do{
                line=fin.readLine();
                if (line!=null)
                {
                    if (m == 366)
                    {
                        data[n]=sum;
                        m = 1 ;
                        n++;
                        sum=0;
                    }
                    int i = Integer.parseInt(line);
                    if (i > req)
                        sum ++;
                    m++;
                    if (n == 99)
                    {
                        data[n]=sum;
                    }
                }
            }while (line!=null);
        }
        else
        {
            int oldreq = req+1855;
            int tank = 1855;
            do{
                line=fin.readLine();
                if (line!=null)
                {
                    if (m == 366)
                    {
                        data[n]=sum;
                        m = 1 ;
                        n++;
                        sum=0;
                        tank=1855;
                    }
                    int i = Integer.parseInt(line);
                    if (i > oldreq)
                    {
                        sum ++;
                        if (tank!=1855)
                        {
                            if (tank+i-oldreq>1855)
                                tank=1855;
                            else
                                tank=tank+i-oldreq;
                        }
                    }
                    else
                    {
                        if (i+tank>oldreq)
                        {
                            sum++;
                            tank = i+tank-oldreq;
                        }
                        else
                            tank=1855;
                    }
                    m++;
                    if (n == 99)
                    {
                        data[n]=sum;
                    }
                }
            }while (line!=null);
        }


        fin.close();
        for (int j=0;j<100;j++)
            System.out.println(data[j]);
    }
}
```

Model development - Simulated Output

Change the first line of “test.txt” for different minimum engine intakes

Days of operation annually for each engine + tank combination is obtained

J316,without tank	J316,with tank	J320,without tank	J320,with tank	J420,without tank	J420,with tank
297	324	257	295	160	192
298	320	252	295	156	194
279	314	240	279	159	186
283	306	248	282	148	184
283	309	238	279	149	187
287	315	249	282	151	185
272	306	237	271	145	184
299	321	256	297	147	194
281	317	244	275	137	167
284	312	243	283	159	190
281	308	243	278	149	189
285	313	243	284	146	190
281	317	250	280	160	197
292	315	247	289	153	197
290	316	248	287	161	193
280	309	239	277	157	184
266	292	227	264	135	170
301	326	267	300	164	205
295	321	263	293	164	204
288	308	258	287	139	185
279	303	245	276	156	189
285	313	242	284	155	197
287	314	262	287	154	193
278	306	245	273	168	201
261	304	223	259	133	180
270	303	238	266	154	190

Model development - Data Analysis

As the engine must work on at least 255.5 days per year, we calculate the mean and standard deviation of each engine and tank combination

We can use t-tests to figure out if each combination satisfies 255.5 working days constraint. Also, the 5th and 95th percentiles are good indications

For J320 without tank, 255.5 is 1 SD away from mean, so 85% chance it cannot satisfy the constraint. Only J316 engine and J320 with tank can satisfy the constraint

	J316,without tank	J316,with tank	J320,without tank	J320,with tank	J420,without tank	J420,with tank
Min working days:	255.5					
Degree of freedom:	99					
H0:	average working days<255.5					
Ha:	average working days>=255.5					
Mean	281.34	310.29	244.18	279.1	151.99	188.23
Standard deviation	8.991825693	7.11421255	9.875364716	8.995509542	9.044776382	9.274549732
t-value:	28.73721187	77.01484826		26.23531206		
p-value:	p < 0.0005	p < 0.0005		p < 0.0005		
5th percentile:	266	292	227	264	135	170
95th percentile:	297	324	257	295	160	192

Base Solution

J320 with tank generates most revenue in present value, at $6,191,533.04

J316 with tank generates most revenue for each dollar invested, at 287%

Peak hr per day:	5.699			
Peak sales per kw per day:	1.1313			
Total sales per kw per day:	3.5763			
Off-peak hr per day:	18.301			
Off-peak sales per kw per day:	2.445			
Total sales per day:	3029.1261	3029.1261		3787.3017
Total sales per year:	$852,214.34	$939,907.54		$1,057,035.90
Capital cost:	$2,000,000.00	$2,050,000.00		$2,550,000.00
Maintenance cost:	$140,000.00	$143,500.00		$178,500.00
Total revenue per year:	$712,214.34	$796,407.54		$878,535.90
IRR:	9%			
Return in PV	$5,086,614.43	$5,874,346.43		$6,191,533.04
Return/Capital Cost	2.543307215	2.865534846		2.428052174
	J316,without tank	J316,with tank		J320,with tank

Sensitivity Analysis - Ideal Case for Storage Tank

The implementation of storage tank cause some uncertainty: there would be days that the tank is not full, and the gas flow requirement is not satisfied even with the storage in tank. We would like to investigate the case when the tank is always full

J410 with tank is still infeasible

The improvement is marginal for J316 and J320

Results are the same

Min working days:	255.5		
Degree of freedom:	99		
H0:	average working days<255.5		
Ha:	average working days>=255.5		
Average:	311.23	281.34	191.06
Standard deviation:	7.097951049	8.991825693	9.45250755
t-value:	78.51561615	28.73721187	
p-value:	p < 0.0005	p < 0.0005	
Peak hr per day:	5.699		
Peak sales per kw per day:	1.1313		
Total sales per kw per day:	3.5763		
Off-peak hr per day:	18.301		
Off-peak sales per kw per day:	2.445		
Total sales per day:	3029.1261	3787.3017	
Total sales per year:	$942,754.92	$1,065,519.46	
Capital cost:	$2,050,000.00	$2,550,000.00	
Maintenance cost:	$143,500.00	$178,500.00	
Total revenue per year:	$799,254.92	$887,019.46	
IRR:	9%		
Return	$5,902,678.19	$6,275,945.44	
Rate of Return:	287.94%	246.12%	
	J316	J320	J420

Sensitivity Analysis - 70% Availability Constraint

What if we disregard the 70% availability constraint?

The optimal solution does not change

Previously infeasible combinations yield lower profit and rate of return than those of the feasible ones

Total sales per day:	3029.1261	3029.1261	3787.3017	3787.3017	5099.8038	5099.8038
Total sales per year:	$852,214.34	$939,907.54	$924,783.33	$1,057,035.90	$775,119.18	$959,936.07
Capital cost:	$2,000,000.00	$2,050,000.00	$2,500,000.00	$2,550,000.00	$2,900,000.00	$2,950,000.00
Maintenance cost:	$140,000.00	$143,500.00	$175,000.00	$178,500.00	$203,000.00	$206,500.00
Total revenue per year:	$712,214.34	$796,407.54	$749,783.33	$878,535.90	$572,119.18	$753,436.07
IRR:	9%					
Return in PV	$5,086,614.43	$5,874,346.43	$4,960,430.18	$6,191,533.04	$2,792,651.51	$4,546,775.38
Return/Capital Cost	2.543307215	2.865534846	1.984172074	2.428052174	0.962983279	1.541279788
	J316,without tank	J316,with tank	J320,without tank	J320,with tank	J420,without tank	J420,with tank

Conclusion

If Oakville Hydro is capital sensitive, buy J316 with tank which gives a profit of $5,874,346.43 and a rate of return of 287% in present value

If Oakville Hydro is capital insensitive, buy J320 with tank which gives a profit of $6,191,533.04