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ENGINEERING SYSTEMS ANALYSIS FOR DESIGN Final Examination, 2007

I will complete this test fairly, without copying from others, a book, or the web.

Please sign your name legibly___________J. Q. Solution______ **(1 point)**

Item	**Points**	
	Possible	**Achieved**
Your Name	**1**	
1 Future Demand for Power	**17**	
2 Power Economics	**35**	
3 Decision Analysis	**40**	
4 Value at Risk and Gain	**30**	
5 Value of Information	**29**	
6 Option Value	**28**	
TOTAL POSSIBLE	**180**	
TOTAL ACHIEVED		
GRADE ON 100% (TOTAL/1.80)		

Structure of the Exam
The questions refer to various aspects of a hypothetical renewal energy project. You will want to start at the beginning and carry on through.

Precision of Answers
Recognizing the great uncertainties associated with future situations, and the dubious value of meaningless significant figures, you will:

GIVE RESULTS USING TWO-DECIMAL PLACE ACCURACY

Grading
The concepts are the focus of the exam. You will earn most of your points by demonstrating that you know what the correct procedures are, and how to use them. You will do this by "running the numbers'. However, in this exam the numbers themselves are not too important – points will be deducted for mistakes, but neither the course nor the exam is focused on arithmetic.

Because the focus is on the concepts, you should clearly indicate how you going about each part of the exam so that we can give you the credit you deserve.

If the numbers are wrong and you have not explained your analysis, we will not be able to give you credit.

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1 Future Demand for Power (17 pts)

You are now investigating the possible future demand for power that you might produce from a prospective renewable energy farm supplying a resort on a Caribbean island.

Your consultants estimate that the demand will

- Start at the rate of 1,000,000 kWh during the first year, based on negotiations with the resort operator;
- Grow at an average rate of 7% per year;
- With a standard deviation of 35%.

To cover a reasonable future without getting into excessive detail, you decide to consider 2 blocks of 4 year periods

Useful formulas:

$p = 0.5 + 0.5 (v/\sigma) \sqrt{\Delta T}$ $u = e^{\sigma \sqrt{\Delta T}}$ $d = 1/u$

a) Using the data table on next page, what are the values for p, u, d ? **(7 pts)**

$p = 0.5 + 0.5(0.07/0.35) \sqrt{4} = 0.7$ (3 pts)

$u = 2.01 \approx 2$ (2 pts)

$d = 0.5$ (2 pts)

b) Fill in the Tables **(10 pts)**

1 pts per correct value.

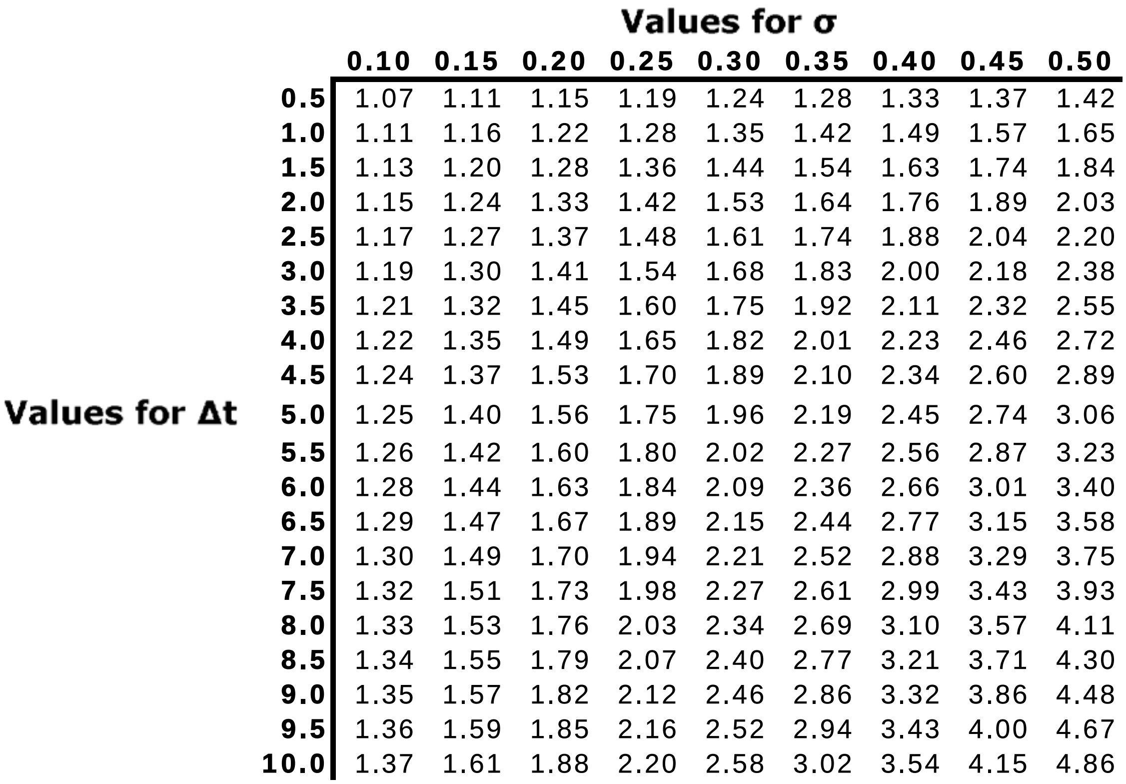
Table of Probabilities at nodes

Year 0	Year 4	Year 8
1	0.7	0.49
	0.3	0.42
		0.09

Table of Demand at end of each 4-year period (in millions of kWh)

1	2	4
	0.5	1
		0.25

Image of Data Table defining formula



		Values for σ								
		0.10	**0.15**	**0.20**	**0.25**	**0.30**	**0.35**	**0.40**	**0.45**	**0.50**
Values for Δt	**0.5**	1.07	1.11	1.15	1.19	1.24	1.28	1.33	1.37	1.42
	1.0	1.11	1.16	1.22	1.28	1.35	1.42	1.49	1.57	1.65
	1.5	1.13	1.20	1.28	1.36	1.44	1.54	1.63	1.74	1.84
	2.0	1.15	1.24	1.33	1.42	1.53	1.64	1.76	1.89	2.03
	2.5	1.17	1.27	1.37	1.48	1.61	1.74	1.88	2.04	2.20
	3.0	1.19	1.30	1.41	1.54	1.68	1.83	2.00	2.18	2.38
	3.5	1.21	1.32	1.45	1.60	1.75	1.92	2.11	2.32	2.55
	4.0	1.22	1.35	1.49	1.65	1.82	2.01	2.23	2.46	2.72
	4.5	1.24	1.37	1.53	1.70	1.89	2.10	2.34	2.60	2.89
	5.0	1.25	1.40	1.56	1.75	1.96	2.19	2.45	2.74	3.06
	5.5	1.26	1.42	1.60	1.80	2.02	2.27	2.56	2.87	3.23
	6.0	1.28	1.44	1.63	1.84	2.09	2.36	2.66	3.01	3.40
	6.5	1.29	1.47	1.67	1.89	2.15	2.44	2.77	3.15	3.58
	7.0	1.30	1.49	1.70	1.94	2.21	2.52	2.88	3.29	3.75
	7.5	1.32	1.51	1.73	1.98	2.27	2.61	2.99	3.43	3.93
	8.0	1.33	1.53	1.76	2.03	2.34	2.69	3.10	3.57	4.11
	8.5	1.34	1.55	1.79	2.07	2.40	2.77	3.21	3.71	4.30
	9.0	1.35	1.57	1.82	2.12	2.46	2.86	3.32	3.86	4.48
	9.5	1.36	1.59	1.85	2.16	2.52	2.94	3.43	4.00	4.67
	10.0	1.37	1.61	1.88	2.20	2.58	3.02	3.54	4.15	4.86

$$Table\ of\ \ values\ \ for\ \ e^{\sigma\sqrt{\Delta t}}$$

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2. Power Economics (35 points)

According to your suppliers, there your renewal energy equipment comes in 2 sizes:

- Big: for 3,000,000 kWh /year
- Small: for 1,500,000 kWh /year

Their corresponding costs of building the plants and producing power are:

	CAPEX $	Operating cost $/ kWh
Big Plant	700,000	0.02
Small Plant	350,000	

a) Define returns to scale.
What is a suitable test to know if a technology exhibits increasing returns to scale?
Does the renewable energy technology represented by the above cost data demonstrate increasing returns to scale? **(8 points)**

Increasing returns to scale occur in a production function (technically efficient) when the production level increases faster than the same change in scale to all input levels. (3 pts)

A suitable test is to look at the sum of the exponents in the production function (when Cobb-Douglas form is assumed). If the sum is higher than 1 we have IRS (3 pts). Alternatively, one could test the technically efficient frontier of the model of the production function for increasing returns to scale (3 pts).

Since we do not have the production function, we cannot determine whether there is IRS (2 pts)

b) Define economies of scale.
What is a suitable test to know if a production situation exhibits economies of scale?
Does the renewable energy technology case represented by the above cost data demonstrate increasing economies scale? **(7 points)**

Economies of scale occur in production when the production level increases faster than the cost of the **optimal** set of inputs required to produce that output level (in a technically efficient process) (3 pts). Alternatively, EoS are demonstrated by decreasing average costs per unit of production (3 pts).

A suitable test (assuming the cost function was derived from a Cobb-Douglas model for the input cost function) is to look at the exponent of the cost function. If the exponent is smaller than 1, or more generally the function is such that cost does not increase as fast as the output, then we have EoS (2 pts). Alternatively, we can check for decreasing unit costs as scale increases (2 pts).

One may infer there is no EoS because the big plant with higher CAPEX produces one kWh at the same CAPEX / kWh ($700,000 / 3,000,000 kWh/year = $0.23 / kWh) than the small plant ($350,000 / 1,500,000 kWh/year = $0.23 / kWh), and same operating cost ($0.02 / kWh). As capacity increases from the small to the big plant, larger capacity does not reduce total production cost when operating at full capacity. (2 pts)

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c) Calculate the costs of meeting the demand using Big and Small alternatives
Remember that each plant has a maximum capacity **(10 points)**

Full credits for correctly entering all 10 values below (0.5 pt per value up to max of 10 pts)

Table of Demand at end of each 4-year period (in millions of kWh) -- from previous analysis

Year 0	Year 4	Year 8
1	2	4
	0.5	1
		0.25

Costs ($, Thousands), at end of 4 year period, for each size of plant

Big Plant (up to 3M kWh)

700	40	60
	10	20
		5

Small plant (up to 1.5M kWh)

350	30	30
	10	20
		5

d) Calculate the net revenue from operations for each plant at the end of the appropriate period **(10 points)**

Assume that the revenues from power will equal $ 0.10 / kWh (close to current US national cost)

Full credits for entering all values correctly (0.5 pt up to a max of 10 pts).

Revenues ($, Thousands) from Operations

Big Plant

0	200	300
	50	100
		25

Small plant

0	150	150
	50	100
		25

Net Revenues from Operations, in last year of 4 year period, for each size of plant

Big Plant

0	160	240
	40	80
		20

Small plant

0	120	120
	40	80
		20

N.B. No points are taken off if students have incorporated CAPEX at t = 0 in the lattice, even though it is not an operating cost.

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3 Decision Analysis (40 points)

Being under pressure to determine which of the two systems should be purchased, you set out to do a decision analysis of the choice between the big and the small plant.

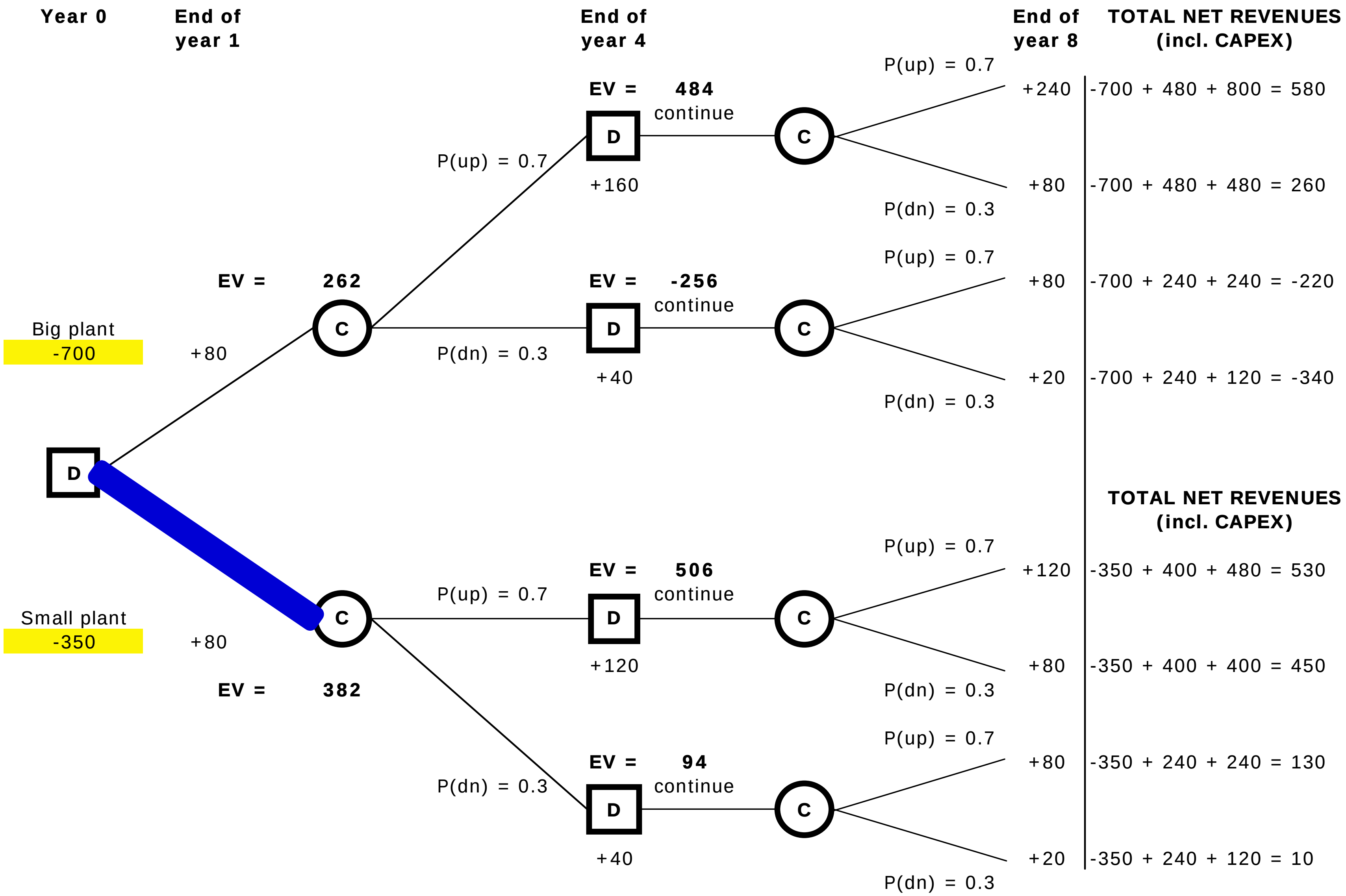
a) Draw the decision tree describing the problem **(8 points)**

Full credits if tree is drawn with appropriate paths (1 pt per path).

b) Enter your information on the probabilities and net revenues at the end of each period **(10 points)**

Full credits if probability values are entered correctly on the tree (0.5 pt per value up to max of 5 pts) and net revenues at the end of each 4 years period are correctly attributed (0.5 pt per value up to max of 5 pts).

See decision tree on next page.


Year 0
End of year 1
End of year 4
End of year 8
TOTAL NET REVENUES (incl. CAPEX)
P(up) = 0.7
EV = 484
continue
+240
-700 + 480 + 800 = 580
D
C
P(up) = 0.7
+160
+80
-700 + 480 + 480 = 260
P(dn) = 0.3
P(up) = 0.7
EV = 262
EV = -256
continue
+80
-700 + 240 + 240 = -220
Big plant
-700
+80
C
P(dn) = 0.3
D
C
+40
+20
-700 + 240 + 120 = -340
P(dn) = 0.3
D
TOTAL NET REVENUES (incl. CAPEX)
P(up) = 0.7
EV = 506
continue
+120
-350 + 400 + 480 = 530
P(up) = 0.7
Small plant
-350
+80
C
D
C
+120
+80
-350 + 400 + 400 = 450
EV = 382
P(dn) = 0.3
P(up) = 0.7
EV = 94
continue
+80
-350 + 240 + 240 = 130
P(dn) = 0.3
D
C
+40
+20
-350 + 240 + 120 = 10
P(dn) = 0.3

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c) Now, estimate the net revenues over each 4 year period associated with each end state of power demand. **For simplicity, omit any discounting of revenues over time.** Use the formula below:
(12 points)

Estimated net revenue over period = 2 [(Revenue at start of period) + (Revenue at end of Period)]

End of 1st 4 year period

Path	Net Revenues
up	480
down	240

This is for Big plant

End of 2nd 4-year period

Path	Net Revenues
Up – up	800
Up – down	480
Down - up	240
Down - down	120

Full credits for entering correct values in tables (1 pt per value up to 12 pts)

The formula above comes from:

Estimated net revenue over period = $\frac{\underline{[(\text{Revenue at start of period}) + (\text{Revenue at end of Period})]}}{2} \times 4$

Therefore, the start and end net revenue values divided by 2 account for the average net revenues over each of the 4 years period, multiplied by 4 to get a cumulative net revenue at the end of the period.

E.g. For the big plant, the up path net operating revenue over years 1-4 is 2 x [160 + 80] = 480 (since demand starts at 1,000,000 kWh, we assume net revenues according to this demand at the start of the first four-years period). The up-up path over years 5-8 gives 2 x [160 + 240] = 800 (assuming the net revenues at the start of the second four-years period is the same as the net revenues at the end of year 4). The same applies for the small plant.

Note also that since we are performing a decision analysis, we do not assume path independence! Hence we explicitly find the cumulative net revenues at the end of all possible paths.

Path	Net Revenues
up	400
down	240

This is for Small plant

Path	Net Revenues
Up – up	480
Up – down	400
Down - up	240
Down - down	120

d) Which technology choice maximizes Expected Net Revenues? **(10 points)**

The small plant (5 pts) maximizes the Expected Net Revenues (incl. CAPEX) with an EV = $382,000 (5 pts).

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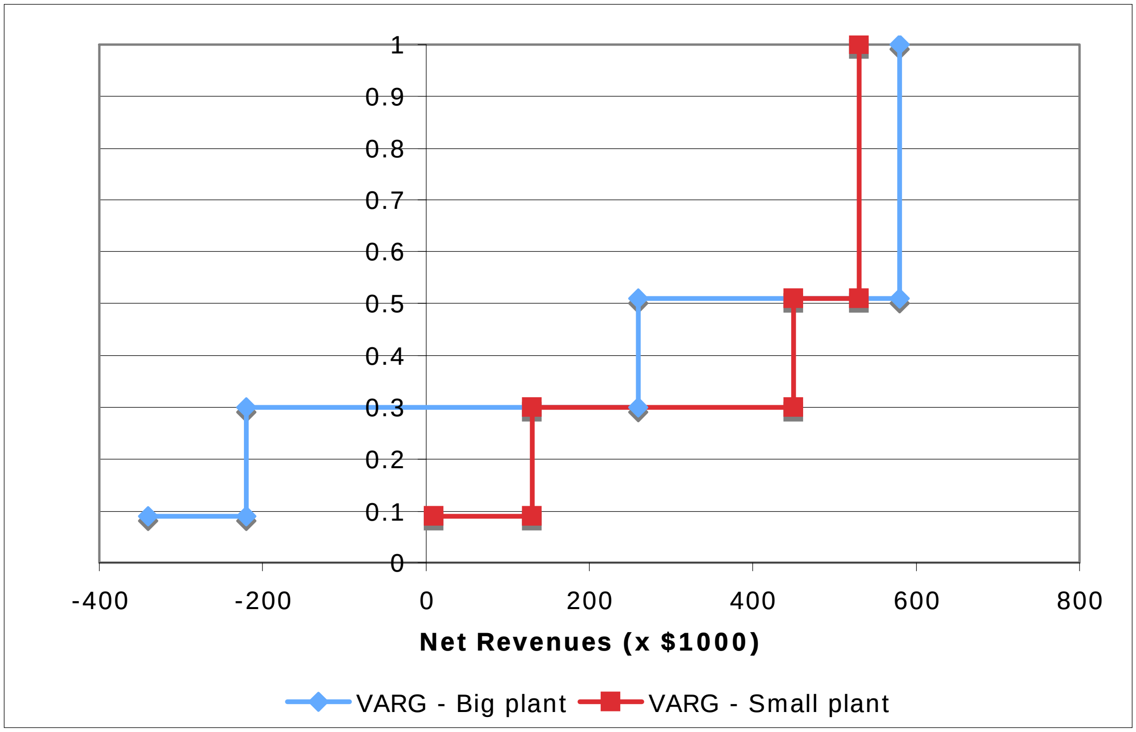
4. Value at Risk and Gain (VARG) (30 pts)

a) Sketch the VARG diagram for each plant. Label axes and grid and draw accurately. **(13 pts)**

The two graph axes must be labeled correctly (3.5 pts for each axis for 7 pts). The net revenues values (8) and associated cumulative probabilities (4) must be shown properly (0.5 per value for 6 pts).



Path	Net Rev (Big)	Net Rev (Small)	Probability	Cum. Prob.
Up-up	580	530	0.49	1.00
Up-down	260	450	0.21	0.51
Down-up	-220	130	0.21	0.30
Down-down	-340	10	0.09	0.09

c) Fill in the Table to compare the two Technologies according to the criteria indicated below **(10 points)**:

Full credits for correct values and assigning which plant is better (0.5 pt per value up to 10 pts).

Criterion	Big Plant	Small Plant	Which better?
Expected Value	262	382	Small plant
CAPEX	700	350	Small plant
B/C = E(V) / CAPEX	962/700 = 1.37	732/350 = 2.09	Small plant
Minimum Value	-340	10	Small plant
Maximum Value	580	530	Big plant
Other you Define			

Note: for simplicity, omit any discounting of revenues over time

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N.B. For the B/C ratio, the original intent is to divide the Expected Value (without CAPEX) by the CAPEX to get a net benefit-cost ratio. Since this is not clear in the writing of the table, no points are taken off if students have divided Expected Value by CAPEX, or used B/C = all benefits / (CAPEX + all oper. costs). Our apologies for the confusion here.

d) Which do you feel is better? Discuss and justify your response **(7 points)**

Students should clearly state their preferred plant (4 pts) and discuss the reasons for this choice (3 pts). The discussion should recognize that the choice is not necessarily "democratic", where the small plant seems to better on four out of five criteria. Indeed, the choice is based on the criterion most important to the manager. An example answer could be: the small plant is chosen over the big plant because it is better at reducing potential losses and has a higher net B/C ratio.

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5. Value of Information (29 points)

You recognize that your preferred choice could lead to problems:

- If you choose the big plant, it may be unprofitable if demand does not grow;
- If you choose the small plant, you may miss out on upside opportunities.

You therefore plan to get additional information that could reduce your uncertainty. To help you organize this, you will use the concept of EVPI.

a) Your boss asks: “What’s this ‘perfect information’ stuff?”? “Nobody’s perfect!” You then explain the concept of EVPI using the following words: **(5 pts)**

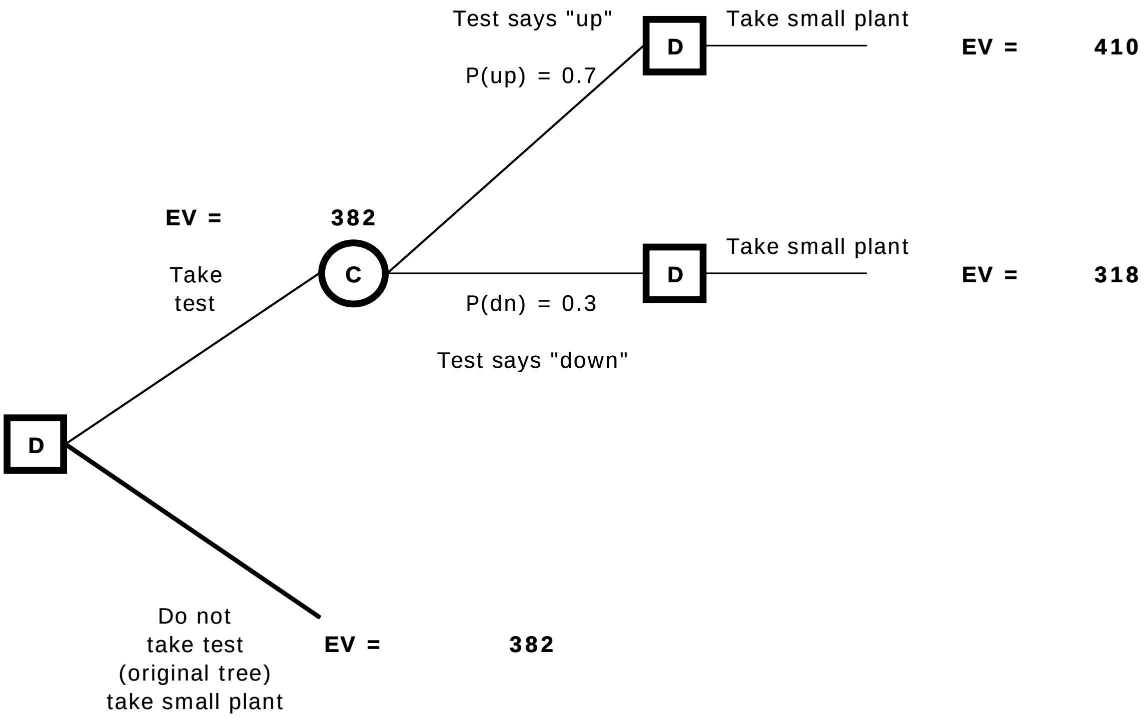
The EVPI is a hypothetical concept (1 pt) that enables us calculate the maximum value of additional information (2 pts) so we can estimate how much it is worth and compare with the real costs of actual tests (1 pt). It is an expected value (1 pt).

b) In this specific case, how might perfect information about whether the growth in the second 4 year period is “up” (if not, it is “down”) change your perception of the decision problem you analyzed in part 3? A descriptive rather than a numerical answer is required here. **(4 points)**

If it is known in advance that demand will be “up” in the second period, this will increase the Expected Net Revenues of each plant (2 pts). It will do so particularly for the big plant, which can take advantage of larger demand (1 pt). Therefore, this might change the choice of technology from the small to the big plant based on the highest Expected Net Revenues (1 pt).

c) Now draw the diagram showing the decision tree associated with the decision to engage in process that gives perfect information about whether the growth in the second 4 year period is “up” (if not, it is “down”) **(8 pts)**

See last page for decision trees depending if test says “up” or “down”. The diagram looks as follows (4 pts for correct branches, 4 pts for correct values):



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c) What is your estimate of EVPI in this case? **(8 pts)**

EVPI = EV(with test) – EV(without test) = 382 – 382 = 0 (8 pts)

d) What is the most money you might justify spending to improve your information? Explain this choice.**(4 pts)**

We would invest nothing (2 pts) since perfect information has no value in this case (2 pts).

6. Option Value (28 points)

The small plant can be expanded! Now let's look into what it might be worth to add another 1,500,000 kWh unit at the end of the first 4 years.
For this expansion, the CAPEX of the second small plant is much less, since you have carefully arranged the site and done a deal with the manufacturer. The CAPEX for the second small increment is now only $200,000.

a) Under what circumstances would this have any value? Explain reasoning. **(6 points)**

The increment may add value compared to the small plant without expansion capability by capturing additional net revenues when demand is up in the second period (6 pts).

b) What might be the operating costs of adding this increment and running it over the period? **(5 points)**

See the modified decision tree in Appendix to incorporate the expansion capability.

The additional plant will be built only if demand was up in the first period since otherwise the resulting up and down states for the second period (1,000,000 kWh in the up state, 250,000 kWh in the down state) can be covered with a small plant. It would not make sense to invest to acquire extra capacity that will not be used (1 pt).

If built after an "up" state in the first period, the demand can either be for 4,000,000 kWh or 1,000,000 kWh at the end of year 8. Hence in the up state it will incur an additional 1,500,000 kWh x 0.02 kWh = $30,000 in operating cost at the end of year 8 when it runs at full capacity (3 pt). Referring to the cost lattices in p. 5, and assuming the same formula as for net revenues as on question 3c), the total additional operating cost over the period should be 2 x [0 + 30] = $60,000. In the down state it will incur no additional operating cost because the existing capacity will provide the required amount of product (1 pt).

c) What might be the extra revenues of adding this increment? **(4 points)**

If built, the increment will generate in the up state an additional $300,000 (2 x [$0 + $150,000]) over the second period (2 pts). In the down state, it will not generate any more revenues (2 pts).

d) What is the expected value of having the increment? **(3 points)**

The increment adds $300,000 - $60,000 = $240,000 in cumulative net revenues using the values from parts b) and c). As seen on the decision tree in Appendix, this is the difference between the cumulative net revenues (without CAPEX) in the up-up state of the expansion case ($400,000 + $720,000 = $1,120,000) and the up-up state of the non-expansion case ($400,000 + $480,000 = $880,000) (1 pt). Thus the increment adds EV = 0.7 x $240,000 + 0.3 x 0 = $168,000 (2 pts).

e) Is the option worth its strike price? **(2 points)**

No (1 pt), since EV = $168,000 < $200,000 (1 pt), which is the cost of acquiring the plant, the option is not worth its strike price and should be left unexercised. The difference (-$32,000) is reflected in the difference of cumulative expected net revenues (including CAPEX) between the expanded and non-expanded cases. This is $474,000 - $506,000 = -$32,000, as seen on the decision tree in Appendix. In the expansion case, the increment costs $200,000 and $168,000 of additional revenues are generated, thus incurring a loss of $32,000, reflected in the difference in EVs including CAPEX.

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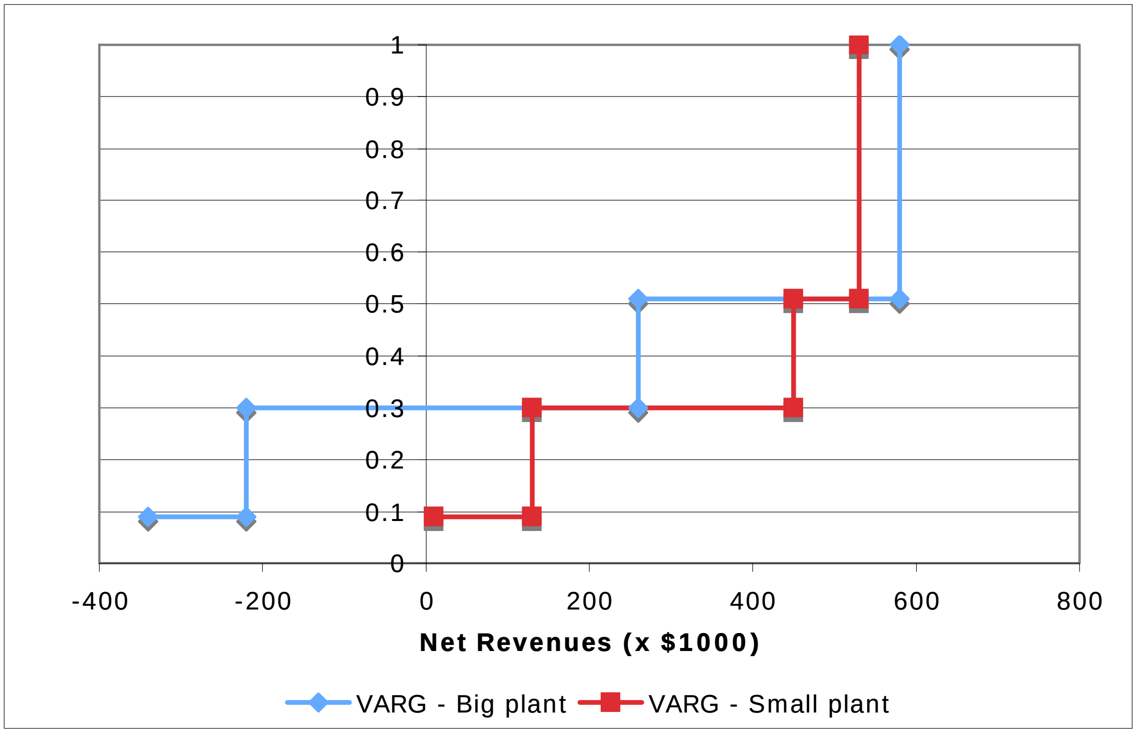
f) How does option to double the installation of the small plant change the VARG you had previously for the small plant? **(8 points)**

Since the option is worth less than its strike price, it would not be exercised (4 pts) and therefore the VARG curve is left unchanged (4 pts).



THANK YOU FOR YOUR PARTICIPATION IN THE CLASS. ALL BEST WISHES!!!!

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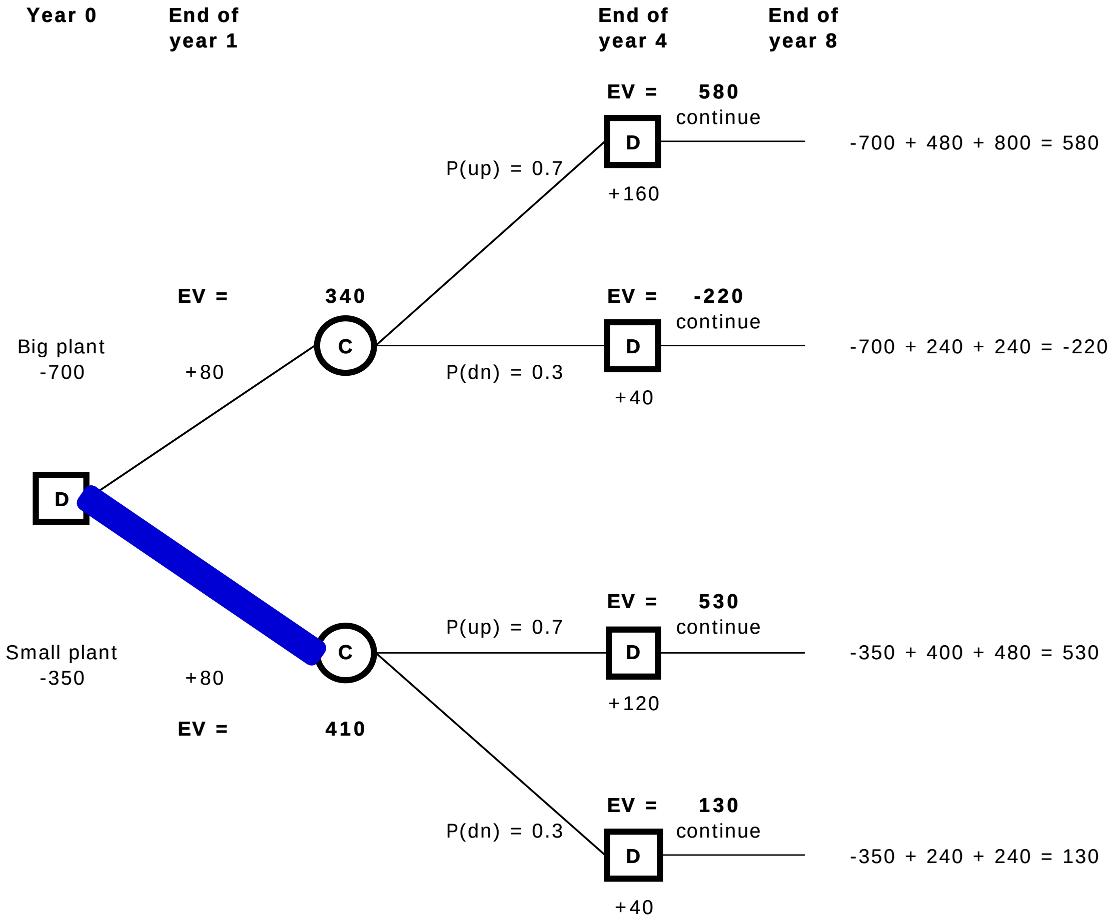
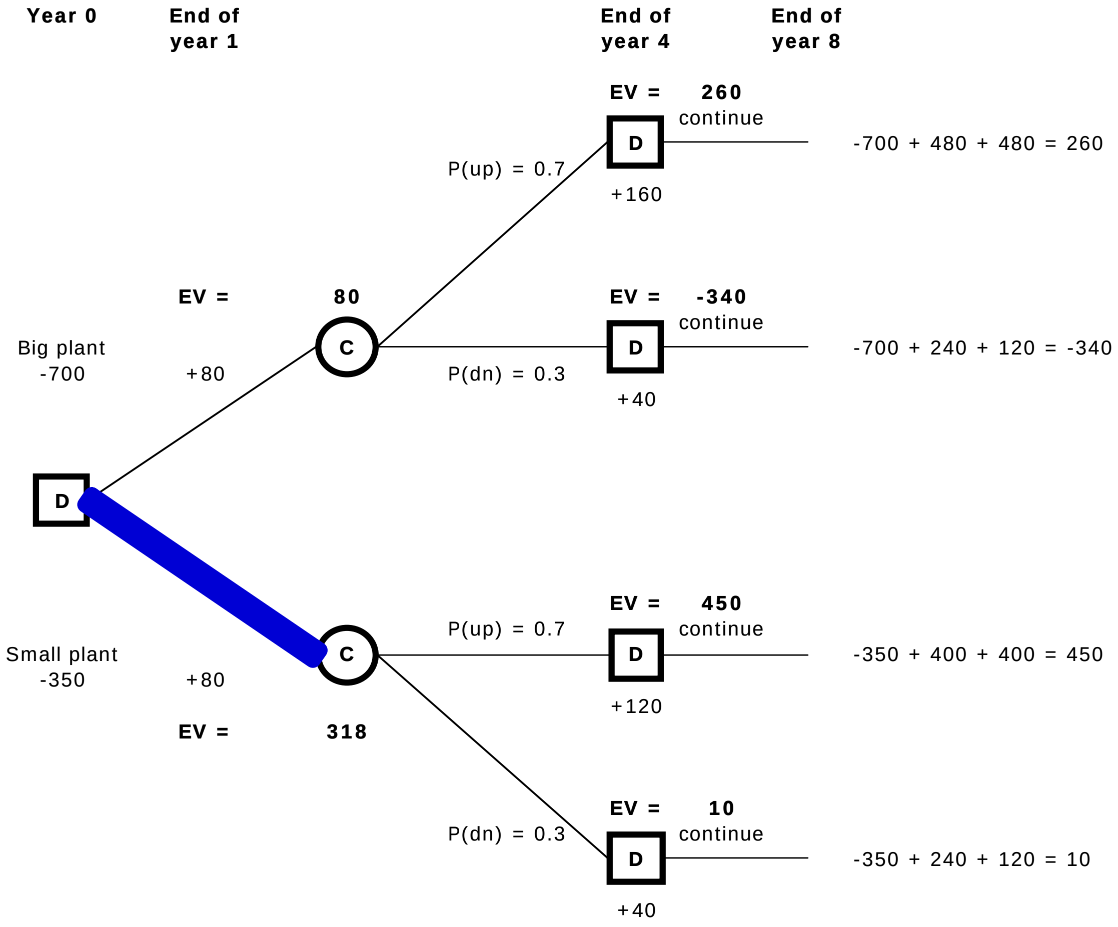
APPENDIX

Separate decision trees for Question 5:

In Question 5, if test says "up", the tree below emerges:



If test says “down”, the tree below emerges:



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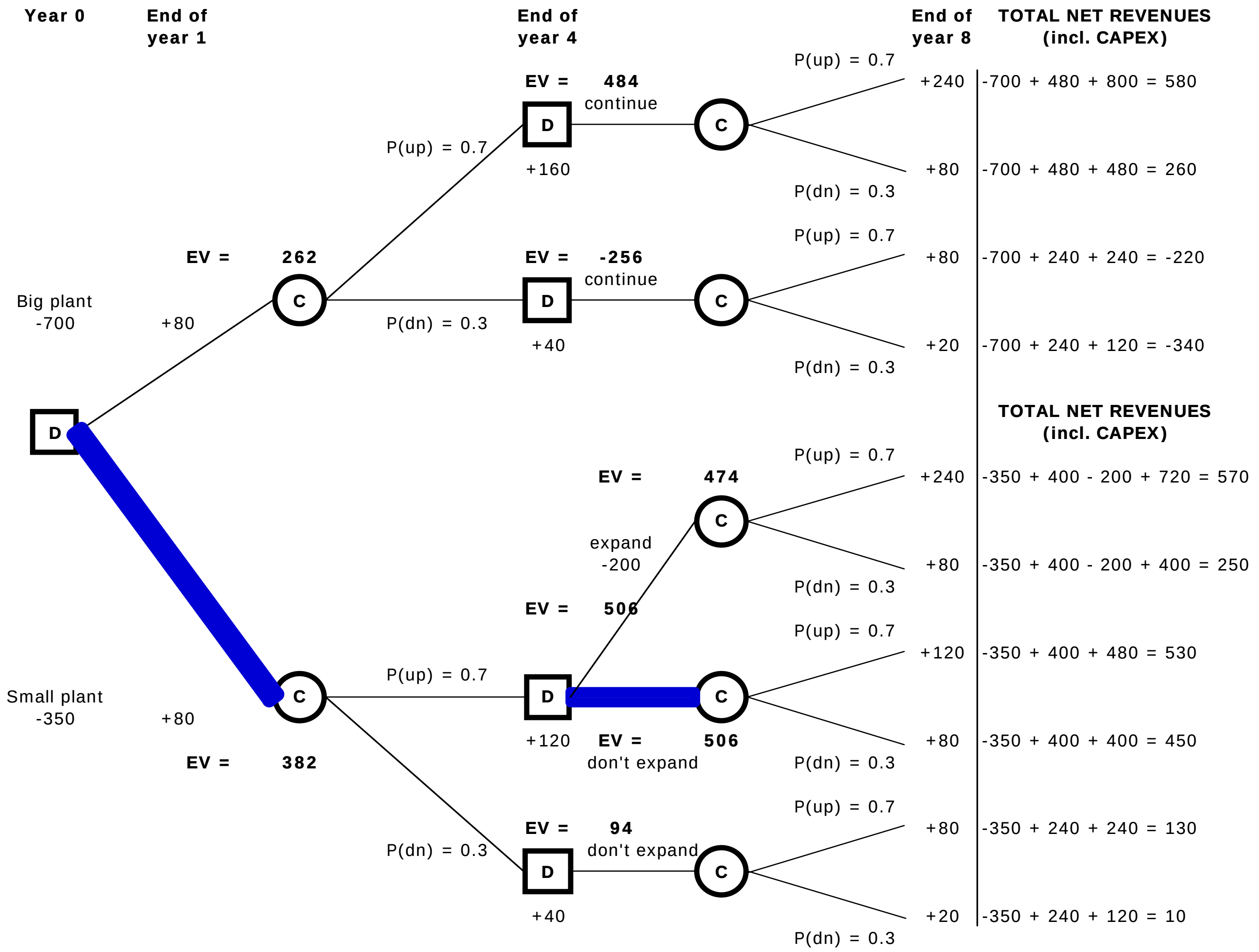
SOLUTION



N.B. There is no point to expand if the demand in the first period is down because in the subsequent upstate we can capture the same up state demand (1) as for the large plant capacity but without incurring the cost of expansion.