ENGINEERING SYSTEMS ANALYSIS FOR DESIGN

D R A F T Final Examination, 2005

Item	Points	
	Possible	Achieved
Your Name	2	
1 Cost Function	18	
2 Engrg Economy Valuation	26	
3 Decision Analysis	18	
4 Value of Information	15	
5 Lattice Development	27	
6 Value at Risk	18	
7 Option Evaluation	56	
TOTAL POSSIBLE	180	
TOTAL ACHIEVED		
GRADE ON 100% (TOTAL/1.80)		

Structure of the Exam
The questions all tie to the design and justification of a proposed project. They take you through the material of the course from the beginning to the end.

The technological part is deliberately simple, to reduce the complexity of the calculations and focus on the concepts of the course.

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 case 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.

Project
You are designing a logistics sorting center. As project manager, you need to be able to justify the design to the decision-making board that can authorize the project.

I have completed this test fairly, without copying from others, a book, or the web.

Please sign your name legibly ____ (2points)

1. Cost Function (18 points)

Your design engineers have come up with a plan for the sorting center project. They have sized it in the traditional way, that is, to provide the maximum capacity projected over its life.

This maximum capacity has been projected at 8 million packages/year, based on an estimated initial load of 2 million packages/year, that would double every 8 years (that is, would grow at about 9% / year compounded).

As you wonder whether if it might be better to roll out the capacity in a couple stages, your staff provides you with their formula for estimating project costs:

Cost of building line = Cost of building + Cost of Equipment
$= 2 + 0.6\,(\text{Capacity})^{2/3}$
The cost is expressed in terms of millions of dollars; the capacity in terms of millions of packages per year.

a) Define the concept of the "cost function" and its connection to the production function. **(4 pts)**

b) Does this cost function define a convex feasible region? Explain your answer. **(3 pts)**

c) Define "economies of scale". How is this different from "increasing returns to scale" ? **(4 pts)**

d) It you knew that the cost function did NOT have economies of scale, how would it affect your thoughts about developing the project in stages? **(4 pts)**

e) Does this cost function exhibit economies of scale? Explain your answer. **(3 pts)**

2 Engineering Economy Valuation (26 pts)

Being pressed for time, you decide to see if you can justify the "base case" project proposed by your design staff. Therefore you do some traditional calculations.
USE ONLY TWO-DECIMAL PLACE ACCURACY FOR THIS AND OTHER CALCULATIONS

As previously, you assume that the
- design is for Capacity = 8 million packages/year = maximum projected demand
- cost formula is: Cost = 2 + 0.6 $(\text{Capacity})^{2/3}$ -- in millions of dollars
- initial demand = 2 million packages/year
- growth rate ~ 9 % /year (doubling every 8 years, that is by $\sqrt{2}$ every 4 years)
- life of project = 16 years

Assume that
- revenues in any 4-year period = 4 x (demand at end of the period) x ($0.4 per 1000 packages)
- revenues are paid in at the end of each period
- the company normally uses a discount rate ~ 20%, which is its estimated WACC

Not having a spreadsheet available, you will do your analysis by filling in the table below.
For simplicity, and in keeping with 2 decimal point accuracy, you can assume:
(1 +0.2) exp(4) =2; and $\sqrt{2}$ = 1.4

Base Case Project

Years	0	1-4	5-8	9-12	13-16
Demand at period end (millions	2				
Revenue for 4 years (millions)					
Cost					
Net Cash Flow					
Discounting Factor at 20%					
Discounted Cash Flow					
Net Present Value					

a) What is your estimate of the project NPV? **(15 pts)**

b) Define pay-back period. Estimate it for the project. **(4 pts)**

c) Define internal rate of return. By looking at the table, what would you estimate it to be? **(3 pts)**

d) One of your engineers asks you to justify the apparently high discount rate. You therefore explain that the WACC is….. **(4 pts)**

3 Decision Analysis (18 pts)

Wondering about the desirability of an alternate design that would roll out the project in 2 phases, you decide to do a simple decision analysis to test the following alternatives:

- Base Case: build full 8 million capacity now
- Phased Case: build 4 million at start, add 4 million at end of the second period (year 8)

The cost of construction is as before: $2 + 0.6\,(\text{Capacity})^{2/3}$

As an experienced professional, you estimate that there is a 10% probability that your company will not be able to obtain the permits to build the second phase in year 8, so that revenues for the "phased case" would be capped for the last 2 periods (years 9-16)

The tables below indicate where new data needs to be inserted (compared to previous table).

Phased Project (with second phase built)

Years	0	1-4	5-8	9-12	13-16
Demand at period end (millions	2				
Revenue for 4 years (millions)					
Cost					
Net Cash Flow					
Discounted Cash Flow					
Net Present Value					

Phased Project (with second phase NOT built, revenues capped)

Years	0	1-4	5-8	9-12	13-16
Sales at period end (millions)	2				
Revenue for 4 years (millions)					
Cost					
Net Cash Flow					
Discounted Cash Flow					
Net Present Value					

a) Draw the decision tree. Fill in all relevant data. **(15 pts)**

b) Which is the better choice? The full project from start or the phased project? **(3 pts)**

4 Value of Information (15 pts)

Thinking about the possibility that the phased alternative is attractive, you decide to estimate whether if would be worthwhile to gather better information on the possibility that a second phase might not be constructed. You plan to do this using EVPI.

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

b) To reinforce the above, you draw the diagram showing the decision tree with EVPI **(5 pts)**

c) What is your estimate of EVPI in this case? **(3 pts)**

d) For any EVPI, what guidance does it give you about the money you might justify spending to improve your information? **(2 pts)**

5 Lattice of Probabilities (27 pts)

After reaching your conclusions regarding the optimal staging of the plant in view of the uncertainty in building the second plant using decision analysis, you start looking into another uncertainty that you had not previously considered: demand uncertainty.

You model the evolution of demand with a binomial lattice, based on these parameters:

- Initial demand = 2 million packages/year
- Annual Growth, v = 9%
- Std Deviation of change in demand over 1 year, σ = 35%

To reduce your calculations, you decide to examine a time horizon of 12 years (and not 16). You are still considering 4 year blocks of time.

Useful formulas:

$p = 0.5 + 0.5 (v/\sigma) \sqrt{\Delta T}$

$u =$ e power$[\sigma \sqrt{\Delta T}]$

$d = 1/u$

a) Give the values you have calculated for p, u, d **(5 pts)**

b) Fill in the Tables **(14 pts)**

Table of Probabilities at nodes

Year 0	Years 1 - 4	Years 5 - 8	Years 9 - 12
1			

Table of Demand at end of period

2			

c) Use the grid to sketch the resulting distribution at the end of the 3rd period (year 12) **(8 pts)**

Image of Data Table defining formula

sigma, σ	0.1									
Δ T	0.5									
						Sigma, σ				
e power[σ vΔT]	1.073271	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5
	0.5	1.07	1.11	1.15	1.19	1.24	1.28	1.33	1.37	1.42
	1	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	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	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	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	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	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	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	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	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	1.37	1.61	1.88	2.20	2.58	3.02	3.54	4.15	4.86

6. Value at Risk (18 pts)

The distribution you have calculated sets off some alarm bells in your head. Although the project could be a big winner, the data also indicate that there is a distinct possibility that the traffic would not justify the capacity planned for the base case design (8 million packages/year).

To illustrate this possibility, you decide to draw up a Value at Risk Diagram for the revenues obtained in the **third period (year 12)**, for these **two situations**:

- Traffic and revenues are as projected for the base case (Exercise 2)
- Traffic has the distribution you have just calculated

For your convenience, the assumptions used to calculate revenue in a period are repeated here:

- revenues in any period = 4 (demand at the end of the period) x ($0.4 per 1000 packages)
- revenues are paid in at the end of each period

a) Enter the revenues in the following table (the 2 left hand columns come from Exercise 5) **(8 pts)**

Probability	Demand	Revenue

b) Sketch the VAR diagram **(6 pts)**

c) In telling your boss what you've been doing, you explain the VAR diagram as follows: **(4 pts)**

7 Option Evaluation (56 points)

You have persuaded your boss that something ought to be done to protect the organization from the possibility of spending money on a lot of capacity that won't be used. You thus need to investigate the possibility of deferring investments in capacity until uncertainty in demand resolves in the years ahead.

However, it's become plain that the idea of building a parallel project 8 years from now is not acceptable. Your boss reports that the decision-making board does not feel it could get public approval for erecting another building – the politics are too difficult.

Thus, you plan to redesign the way you will install the sorting center, so that you can actually expand it in the future. Since the problem is a new building, you decide to investigate how much more you can afford to spend *today* in erecting a larger building, so that you are able to install more capacity in the future without having to erect a building then. You realize you are thus building a real option "in" the system.

The extra cost of the bigger building will be **X**, so that:

- the initially installed system will cost: (2 + **X**) + 0.6 (Capacity) $^{2/3}$
- But then, increasing capacity will cost less: 0.6 (Capacity) $^{2/3}$

Your task is to estimate what the value of having this flexibility would be, that is, to estimate how much increase in expected value would be available to justify the expenditure of **X.**

You decide to compare two cases of building in year 0 the:

- "full" project, with total capacity = 8.
- "half" project, with capacity = 4, but with a bigger building that allows you to expand to a total capacity of 8 at the end of the second period (in year 8).

Being pressed for time, you:

- simplify your analysis by neglecting what happens in the 4th period (years 13-16) because the impact of anything occurring in year 16 when discounting at 20% is less than 10%
- use the data on probability distribution you have generated in Exercise 5

Assume that if you decide to exercise the option to expand at end of second period (in year 8), you immediately:

- incur the construction costs
- obtain the expanded project (so that the revenues for the expanded project are applied to the following 4-year period).

a) On your way to calculate the option value for the project, the Vice-President (Finance) challenges you: "how can you be doing options analysis? I bet you don't even know what "arbitrage-enforced pricing" is!. But you carefully show that you do understand this concept, explaining it as follows **(6 pts)**

b) You also tell him why you **do not** plan to base your analysis on "arbitrage-enforced pricing" **(4 pts)**

c) First, you calculate the net present value of the base case. **(15 pts)**

Specifically, you use the following table to do this in 2 phases:

1. You construct a lattice of the value of the having a capacity = 8. Remember that the value at every node will be the revenue at that node, plus the expected value from the two succeeding nodes, appropriately discounted according to the formulas below:

2. You deduct the cost of the initial construction, and thus obtain the NPV of the base case.

Years	0	1-4	5-8	9-12
Demand at end of period (Exercise 5 b)	2			
Revenue = (0.3) (4) Demand (in millions)	0			
Remember! Sales capped at 8 million				
P.Value of Having Capacity = 8 in each node				
Cost				
Net Present Value				

d) You now consider building the "half" project, with the larger building: construct the lattice for the value of having a capacity = 4 **(10 pts)**

Revenue = (0.3) (4) Demand (in millions)	0			
Remember! Sales capped at 4 million				
P. Value of Having Capacity = 4 in each node				

e) Now calculate the value of starting with the smaller capacity and expanding it optimally – **which can only be done in year 8**. **(15 pts)**

Again, you do this in 2 phases

1. You construct a lattice of the value of the having a flexible system
2. You deduct the cost of the initial construction of smaller system, and thus obtain the NPV of the flexible system

Remember that owning the smaller, "half" project, gives you the right but not the obligation to expand it at the end of the second period (at the additional construction cost = 0.6 $(\text{Capacity})^{2/3}$), thus obtaining the 8 million capacity facility.

Therefore, the value of the small capacity (4 million) at each node will be the sum of the current revenue (calculated in part d), plus the expected value of next period, if you exercise your expansion option optimally. Do not forget that expansion has a cost.

P. Value of Flexible System				
Cost of initial construction of smaller system				
Net Present Value				

f) Give the optimal exercise decision rules at end of second period (in year 8) **(6 pts)**

Year 0	Year 4	Year 8	Year 12
	No change		No change
	No change		No change
			No change
			No change

THANK YOU FOR YOUR PARTICIPATION. ALL BEST WISHES!!!!