37345

Quantitative Management Practice

UTS: FACULTY OF SCIENCE
School of Mathematical and Physical Sciences

ASSIGNMENT SUBMISSION SHEET – Group

Group Members and, summary of contribution by each including sections and percentage -

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I have carefully read, understood, and have taken into account all requirements and guidelines for assessment and referencing in the subject outline. I affirm that this assignment is my own work; and that is has not been previously submitted for assessment; that al material which is quoted is accurately indicated as such; and that I have acknowledged all sources used fully and accurately according to the guidelines given in the subject guide. I am fully aware that failure to comply with these requirements is a form of cheating and could result in disciplinary action.

UNIVERSITY OF TECHNOLOGY, SYDNEY

37345 Quantitative Management Practice

Autumn Semester 2024
Assessment 3: Report

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Introduction

This report aims to provide a project management plan for Ewing Natural Gas from the perspective of Cliff Erland, the Manager for Project Development. Cliff will use quantitative management methods to balance capital expenditures, expected revenues, and risk control, ensuring that capital expenditures stay within the fixed budget while maximizing expected revenues and keeping risks manageable.

The report includes all 12 projects from three functional areas. Each project outlines capital expenditures, NPF, and budget expenditures for the next three years. The budget constraints specify that annual expenditures must not exceed $4 billion, and the total three-year budget must not exceed $10 billion. Although not all projects will be approved, no functional area should have all its projects rejected.

Solution approach

1. Deterministic case.

When disregarding any uncertainties, this problem can be treated as a linear optimization problem.

First, parameters are set based on the given data. Assume there are N projects, each $project_i$ corresponding to $Capex_{iy}$, and NPV_i. There are a total of three functional areas, with budgets for three years being B_y , and a total budget of B_t. Set x as

$$x_i = \begin{cases} 1, & if\ the\ project_i\ is\ in\ the\ plan \\ 0, & if\ the\ project_i\ is\ not\ in\ the\ plan \end{cases}$$

Therefore, the objective function can be derived as follows:

$$Max \sum_{i=1}^{N} NPV_i \times x_i$$

The constrain is

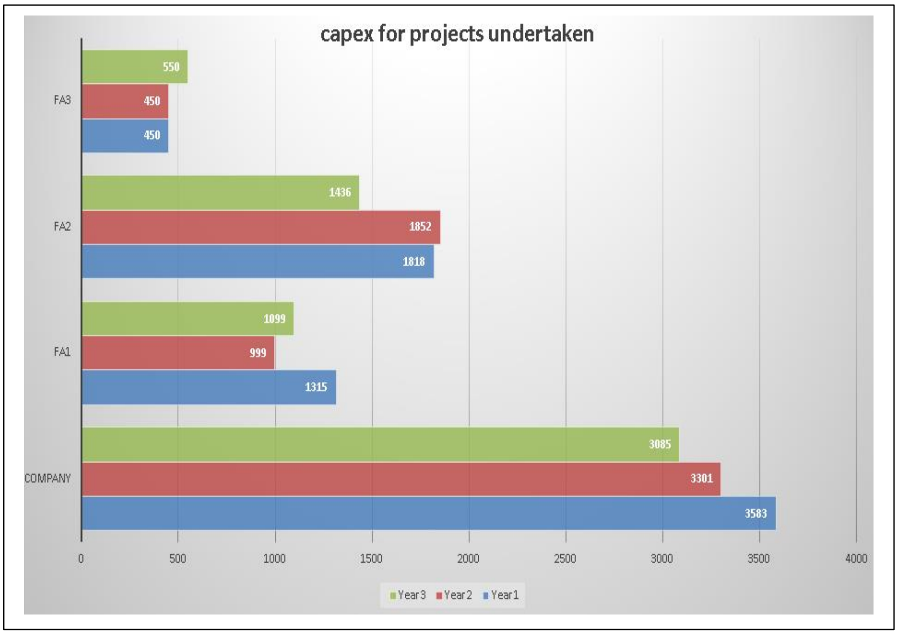
$$\sum_{i=1}^{N} Capex_{iy} \times \leq B_y$$

$$\sum_{y=1}^{3} \square \sum_{i=1}^{N} Capex_{iy} \times \leq B_t$$

Thus, based on the objective function and constraints, set up Excel and use the Simplex LP method in Solver to solve it. Here, x_i is the changing variable and is in binary form (1,0).

The results obtained are as follows: **the total NPV is 1769**, with annual expenditures and the total three-year expenditure being B_1 = 3583, B_2 =3301, and B_3 = 3085, respectively. The total budget B_t = 9969, and a total of 9 projects are included in the plan.

Decisions	
Project index	Undertake project?
1	1
2	1
3	0
4	1
5	1
6	0
7	1
8	1
9	1
10	1
11	1
12	0
Totals	9



In this solution, disregarding any uncertainties, all capital expenditures do not exceed the approved limits.

Limits for company capital expenditures				
	Year 1	Year 2	Year 3	Total
Limit	4000	4000	4000	10000
	>=	>=	>=	>=
Total CAPEX	3583	3301	3085	9969

2. Risk evaluation

When all expenditures are adjusted to follow a beta-PERT distribution, the original data represents the most likely value. The maximum value is 30% higher than the most likely value, and the minimum value is 15% lower than the most likely value. Correspondingly, the NPV will also be adjusted. In this case, the original data represents the most likely value, the maximum value is 15% higher than the most likely value, and the minimum value is 20% lower than the most likely value.

First, First, set the Capex and NPV in the original data to the most likely values.
$Capex_{iy} = mode_{Ciy}$,$and\ NPV_j = mode_{Nj}$.

Second, set the maximum and minimum values, and use these values to calculate the mean.
$Max_{Ciy} = 1.3 \times mode_{Cij},\qquad Min_{Ciy} = 0.85 \times mode_{Ciy},$
$Max_j = 1.15 \times modej, Min_j = 0.8 \times mode_j$

The formula for calculating the mean is:

$$mean = \frac{\text{Minimum Value} + 4 \times \text{Most Likely Value} + \text{Maximum Value}}{6}$$

Then, based on the formula, calculate Alpha 1 and Alpha 2, and finally, in Excel, calculate the sample.

The formulas for Alpha 1 and Alpha 2 are as follows:

$$\text{Alpha 1} = \frac{6 \times (mean - \min)}{\max - min}$$

$$\text{Alpha 1} = \frac{6 \times (max - \text{mean})}{\max - min}$$

Sample = $Min + BETAINV(RAND(), alpha\ 1, alpha\ 2) * (\mathrm{m}ax — \mathrm{m}in)$

Then, all the original data (Capex and NPV) were replaced with beta-PERT distributions using the above methods and formulas.

Inputs	All values in $ millions		beta-PERT distribution						
Project index	Functional Area (FA)	Capex Year 1	min	max	most likel	mean μ	Alpha 1	Alpha 2	Sample
1	FA1	250.00	212.500	325.000	250.000	256.250	2.333	3.667	296.351
2	FA1	165.00	140.250	214.500	165.000	169.125	2.333	3.667	190.413
3	FA1	50.00	42.500	65.000	50.000	51.250	2.333	3.667	57.175
4	FA1	750.00	637.500	975.000	750.000	768.750	2.333	3.667	754.804
5	FA1	150.00	127.500	195.000	150.000	153.750	2.333	3.667	162.636
6	FA2	500.00	425.000	650.000	500.000	512.500	2.333	3.667	456.225
7	FA2	750.00	637.500	975.000	750.000	768.750	2.333	3.667	714.793
8	FA2	800.00	680.000	1040.000	800.000	820.000	2.333	3.667	790.566
9	FA2	268.00	227.800	348.400	268.000	274.700	2.333	3.667	249.240
10	FA3	100.00	85.000	130.000	100.000	102.500	2.333	3.667	92.893
11	FA3	350.00	297.500	455.000	350.000	358.750	2.333	3.667	399.674
12	FA3	1500.00	1275.000	1950.000	1500.000	1537.500	2.333	3.667	1588.043

Inputs			beta-PERT distribution						
Project index	Functional Area (FA)	Capex Year 2	min	max	most likel	mean μ	Alpha 1	Alpha 2	Sample
1	FA1	100.00	85.000	130.000	100.000	102.500	2.333	3.667	92.450
2	FA1	99.00	84.150	128.700	99.000	101.475	2.333	3.667	116.555
3	FA1	100.00	85.000	130.000	100.000	102.500	2.333	3.667	115.209
4	FA1	500.00	425.000	650.000	500.000	512.500	2.333	3.667	503.925
5	FA1	300.00	255.000	390.000	300.000	307.500	2.333	3.667	291.027
6	FA2	150.00	127.500	195.000	150.000	153.750	2.333	3.667	158.252
7	FA2	750.00	637.500	975.000	750.000	768.750	2.333	3.667	734.574
8	FA2	700.00	595.000	910.000	700.000	717.500	2.333	3.667	703.939
9	FA2	402.00	341.700	522.600	402.000	412.050	2.333	3.667	440.990
10	FA3	200.00	170.000	260.000	200.000	205.000	2.333	3.667	199.308
11	FA3	250.00	212.500	325.000	250.000	256.250	2.333	3.667	259.815
12	FA3	400.00	340.000	520.000	400.000	410.000	2.333	3.667	365.458

Inputs			beta-PERT distribution						
Project index	Functional Area (FA)	Capex Year 3	min	max	most likel	mean μ	Alpha 1	Alpha 2	Sample
1	FA1	100.00	85.000	130.000	100.000	102.500	2.333	3.667	92.817
2	FA1	99.00	84.150	128.700	99.000	101.475	2.333	3.667	91.130
3	FA1	200.00	170.000	260.000	200.000	205.000	2.333	3.667	199.510
4	FA1	300.00	255.000	390.000	300.000	307.500	2.333	3.667	259.771
5	FA1	600.00	510.000	780.000	600.000	615.000	2.333	3.667	642.881
6	FA2	150.00	127.500	195.000	150.000	153.750	2.333	3.667	166.487
7	FA2	300.00	255.000	390.000	300.000	307.500	2.333	3.667	289.065
8	FA2	600.00	510.000	780.000	600.000	615.000	2.333	3.667	663.038
9	FA2	536.00	455.600	696.800	536.000	549.400	2.333	3.667	580.882
10	FA3	400.00	340.000	520.000	400.000	410.000	2.333	3.667	389.477
11	FA3	150.00	127.500	195.000	150.000	153.750	2.333	3.667	178.257
12	FA3	400.00	340.000	520.000	400.000	410.000	2.333	3.667	370.626

Project index	Functional Area (FA)		beta-PERT distribution						
		NPV	min	max	most likel	mean μ	Alpha 1	Alpha 2	Sample
1	FA1	60.00	48.000	69.000	60.000	59.500	3.286	2.714	67.7995
2	FA1	59.40	47.520	68.310	59.400	58.905	3.286	2.714	67.2114
3	FA1	40.00	32.000	46.000	40.000	39.667	3.286	2.714	36.342
4	FA1	310.00	248.000	356.500	310.000	307.417	3.286	2.714	308.183
5	FA1	165.00	132.000	189.750	165.000	163.625	3.286	2.714	174.64
6	FA2	90.00	72.000	103.500	90.000	89.250	3.286	2.714	80.7522
7	FA2	410.00	328.000	471.500	410.000	406.583	3.286	2.714	447.434
8	FA2	280.00	224.000	322.000	280.000	277.667	3.286	2.714	273.977
9	FA2	254.60	203.680	292.790	254.600	252.478	3.286	2.714	284.468
10	FA3	100.00	80.000	115.000	100.000	99.167	3.286	2.714	90.2014
11	FA3	130.00	104.000	149.500	130.000	128.917	3.286	2.714	130.282
12	FA3	340.00	272.000	391.000	340.000	337.167	3.286	2.714	335.049

Using the parameters min, mode, max, and the formula

$$mode + BETAINV(RAND(\,), \alpha_1, \alpha_2) \times (max - \min),$$

create 1000 iteration samples for each year and NPV in the form of beta-PERT distributions.

Using the project plans identified in Q1, apply the iteration samples to calculate the annual Capex for three years, generating 1000 simulated data points for each year. Sum these to obtain the total Capex for the three years. Similarly, calculate the simulated NPV data in the same manner.

According to the annual budget expenditure cap of $4 billion and the three-year total expenditure cap of $10 billion, determine whether each simulation data point exceeds the budget, exceeds the expenditure cap, or exceeds the expenditure cap by more than 5%. Similarly, using the project plans identified in Q1, calculate the simulated NPV iteration data.

Simulation of Total CAPEX Year 1			
Iteration	Total Capex	Over the Budget	% over the budget
1	3573.05953	0	0
2	3570.74253	0	0
3	3667.05406	0	0
4	3586.70843	0	0
5	3723.99432	0	0
6	3681.49779	0	0
7	3699.3607	0	0
8	3621.86963	0	0
9	3606.30624	0	0
10	3607.54253	0	0
11	3478.41255	0	0
12	3873.57652	0	0
13	3721.8175	0	0
14	3598.57748	0	0
985	3716.13339	0	0
986	3601.58118	0	0
987	3590.79923	0	0
988	3781.04404	0	0
989	3524.19416	0	0
990	3873.38635	0	0
991	3662.64477	0	0
992	3581.40635	0	0
993	3794.48963	0	0
994	3491.87359	0	0
995	3627.68098	0	0
996	3615.14383	0	0
997	3710.39142	0	0
998	3692.81003	0	0
999	3539.14227	0	0
1000	3698.83299	0	0

Simulation of Total CAPEX Year 2			
Iteration	Total Capex	Over the Budget	% over the budget
1	3488.664073	0	0
2	3329.281796	0	0
3	3360.057323	0	0
4	3106.158094	0	0
5	3447.742145	0	0
6	3348.47971	0	0
7	3482.375069	0	0
8	3504.031805	0	0
9	3355.352071	0	0
10	3413.537456	0	0
11	3469.868494	0	0
12	3465.991559	0	0
13	3400.380227	0	0
14	3451.286242	0	0
985	3419.846771	0	0
986	3374.122478	0	0
987	3381.261313	0	0
988	3446.674588	0	0
989	3516.093589	0	0
990	3213.630133	0	0
991	3400.267016	0	0
992	3451.766172	0	0
993	3463.32303	0	0
994	3348.938147	0	0
995	3340.475254	0	0
996	3344.273275	0	0
997	3413.625755	0	0
998	3421.046762	0	0
999	3328.580065	0	0
1000	3392.139136	0	0

Simulation of Total CAPEX Year 3			
Iteration	Total Capex	Over the Budget	% over the budget
1	3074.4195	0	0
2	3273.54616	0	0
3	3080.99702	0	0
4	3080.94012	0	0
5	3221.92478	0	0
6	3182.18935	0	0
7	3283.5102	0	0
8	3315.94363	0	0
9	3305.30158	0	0
10	3125.04945	0	0
11	3083.62072	0	0
12	3143.74722	0	0
13	3101.48449	0	0
14	3104.463	0	0
985	3053.27746	0	0
986	3230.60715	0	0
987	3050.57815	0	0
988	3257.83999	0	0
989	3281.3817	0	0
990	2999.62223	0	0
991	3303.54499	0	0
992	3220.67036	0	0
993	3031.16848	0	0
994	3177.25902	0	0
995	3194.97212	0	0
996	3071.9586	0	0
997	3098.22857	0	0
998	3135.39677	0	0
999	3168.822	0	0
1000	3226.7098	0	0

Simulation of Total CAPEX Total			
Iteration	Total Capex	Over the Budget	% over the budget
1	10136.1431	1	0
2	10173.5705	1	0
3	10108.1084	1	0
4	9773.80664	0	0
5	10393.6612	1	0
6	10212.1668	1	0
7	10465.246	1	0
8	10441.8451	1	0
9	10266.9599	1	0
10	10146.1294	1	0
11	10031.9018	1	0
12	10483.3153	1	0
13	10223.6822	1	0
14	10154.3267	1	0
985	10189.2576	1	0
986	10206.3108	1	0
987	10022.6387	1	0
988	10485.5586	1	0
989	10321.6694	1	0
990	10086.6387	1	0
991	10366.4568	1	0
992	10253.8429	1	0
993	10288.9811	1	0
994	10018.0708	1	0
995	10163.1284	1	0
996	10031.3757	1	0
997	10222.2457	1	0
998	10249.2536	1	0
999	10036.5443	1	0
1000	10317.6819	1	0

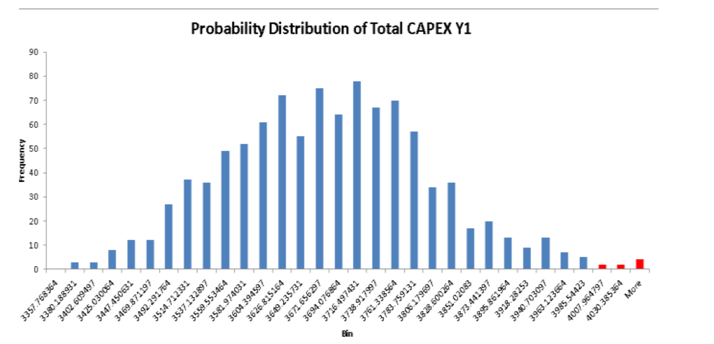
Simulation of Total NPV	
Iteration	Total NPV
1	1883.024256
2	1698.506265
3	1888.710976
4	1736.421663
5	1701.368549
6	1657.375543
7	1831.123589
8	1777.911656
9	1692.616799
10	1797.514176
11	1889.57
12	1769.700281
13	1758.6535
14	2031.300828
985	1795.403367
986	1714.411855
987	1734.815929
988	1739.457441
989	1837.592319
990	1946.225791
991	1811.052692
992	1793.869228
993	1752.030404
994	1862.286471
995	1693.50632
996	1765.549587
997	1764.626364
998	1835.975804
999	1864.783125
1000	1647.902163

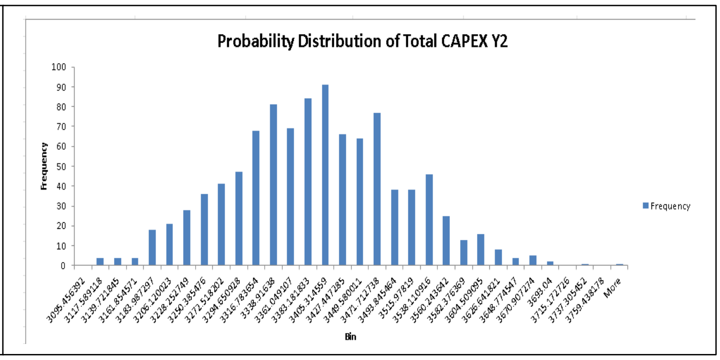
This way, the risk of exceeding the budget and the risk of exceeding the budget by more than 5% can be calculated based on the results obtained from the simulated iterative sample data.

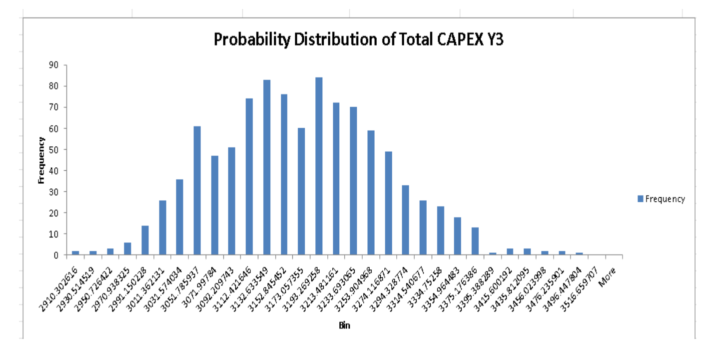
	year 1	year 2	year 3	Total
Over the budget risk	0.40%	0.00%	0.00%	88.70%
5% over the budget risk	0.00%	0.00%	0.00%	7.20%

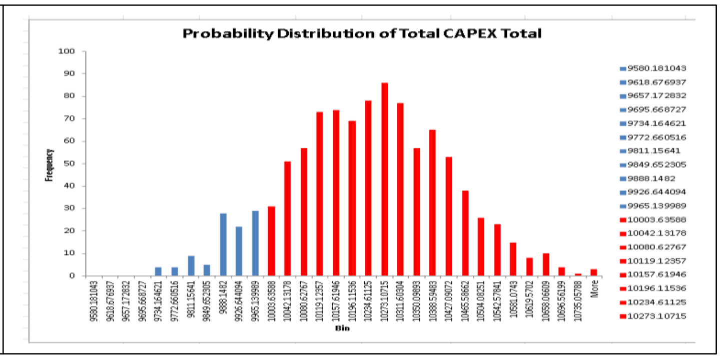
From the results, it can be seen that while the risk of exceeding the budget is very low for individual years, with only 0.4% in the first year, the risk of total expenditure over the three years exceeding the budget is very high. There is an 88.7% chance that the total expenditure over three years will exceed the budget and a 7.2% risk of exceeding the budget by 5%. This result is significantly inconsistent with the findings obtained in Q1.

CAPEX Y1		Total CAPEX Y2		Total CAPEX Y3		Total CAPEX Total	
Bin	*Frequency*	*Bin*	*Frequency*	*Bin*	*Frequency*	*Bin*	*Frequency*
3357.768364	0	3095.456392	0	2910.302616	2	9580.181043	0
3380.188931	3	3117.589118	4	2930.514519	2	9618.676937	0
3402.609497	3	3139.721845	4	2950.726422	3	9657.172832	0
3425.030064	8	3161.854571	4	2970.938325	6	9695.668727	0
3447.450631	12	3183.987297	18	2991.150228	14	9734.164621	4
3469.871197	12	3206.120023	21	3011.362131	26	9772.660516	4
3492.291764	27	3228.252749	28	3031.574034	36	9811.15641	9
3514.712331	37	3250.385476	36	3051.785937	61	9849.652305	5
3537.132897	36	3272.518202	41	3071.99784	47	9888.1482	28
3559.553464	49	3294.650928	47	3092.209743	51	9926.644094	22
3581.974031	52	3316.783654	68	3112.421646	74	9965.139989	29
3604.394597	61	3338.91638	81	3132.633549	83	10003.63588	31
3626.815164	72	3361.049107	69	3152.845452	76	10042.13178	51
3649.235731	55	3383.181833	84	3173.057355	60	10080.62767	57
3671.656297	75	3405.314559	91	3193.269258	84	10119.12357	73
3694.076864	64	3427.447285	66	3213.481161	72	10157.61946	74
3716.497431	78	3449.580011	64	3233.693065	70	10196.11536	69
3738.917997	67	3471.712738	77	3253.904968	59	10234.61125	78
3761.338564	70	3493.845464	38	3274.116871	49	10273.10715	86
3783.759131	57	3515.97819	38	3294.328774	33	10311.60304	77
3806.179697	34	3538.110916	46	3314.540677	26	10350.09893	57
3828.600264	36	3560.243642	25	3334.75258	23	10388.59483	65
3851.02083	17	3582.376369	13	3354.964483	18	10427.09072	53
3873.441397	20	3604.509095	16	3375.176386	13	10465.58662	38
3895.861964	13	3626.641821	8	3395.388289	1	10504.08251	26
3918.28253	9	3648.774547	4	3415.600192	3	10542.57841	23
3940.703097	13	3670.907274	5	3435.812095	3	10581.0743	15
3963.123664	7	3693.04	2	3456.023998	2	10619.5702	8
3985.54423	5	3715.172726	0	3476.235901	2	10658.06609	10
4007.964797	2	3737.305452	1	3496.447804	1	10696.56199	4
4030.385364	2	3759.438178	0	3516.659707	0	10735.05788	1
More	4	More	1	More	0	More	3









The summary of the simulated data distribution for annual Capex, total Capex over three years, and NPV can be obtained.

Summary measures for simulation below	Total Capex year 1	Total Capex year 2	Total Capex year 3	Total Capex 3 years	NPV
Mean of total Capex	3673.5208	3384.7995	3164.5351	10222.8553	1783.5639
Standard Deviation	116.8583	108.8325	99.4599	186.0736	91.8876
Min of	3350.7543	3076.0136	2847.7456	9696.4736	1480.5006
Max of	4140.3057	3841.4006	3477.8560	10810.7337	2031.3008

Using the formula to calculate the 95% confidence interval:

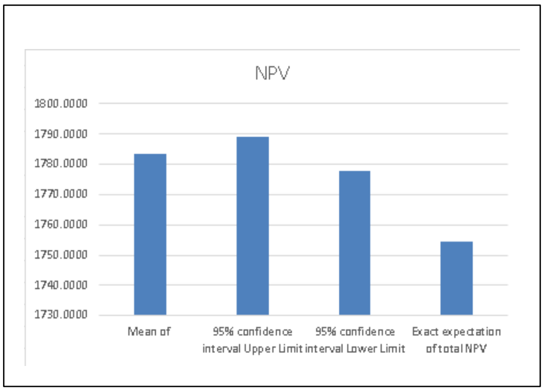
$CI = mean \ \pm 1.96 \times \frac{Standard\ Deviation}{\sqrt{1000}}$, 1000 is the sample size (n)

95% confidence interval for expected	Total Capex year 1	Total Capex year 2	Total Capex year 3	Total Capex 3 years	NPV
Upper Limit	3680.763713	3391.544964	3170.699692	10234.38829	1789.259198
Lower Limit	3666.277809	3378.053952	3158.37052	10211.32236	1777.868691

The "Exact expectation of total NPV" is obtained by multiplying the planned project implementation schemes from Q1 with the mean values from the NPV beta-PERT distribution and summing them up. **And the value is: 1754.258333**

Compare the sample average of the total NPV and its confidence interval with the exact expectation of the total NPV. The exact expectation of the total NPV is below the limit.

	NPV
Mean of	1783.5639
95% confidence interval Upper Limit	1789.259198
95% confidence interval Lower Limit	1777.868691
Exact expectation of total NPV	1754.258333



3. Based on the selection of the optimal solution under uncertainty

According to the requirements, the objective is to maximize the average total NPV while ensuring that the probability of capital expenditures staying within each budget range is at least 0.95. Additionally, each functional area should have at least one project approved. Therefore, the following can be concluded:
Assume there are N projects, each $project_i$ corresponding to $Capex_{iy}$, and NPV_i. There are a total of three functional areas, with budgets for three years being B_y , and a total budget of B_t. Set x as

$$x_i = \begin{cases} 1, & if\ the\ project_i\ is\ in\ the\ plan \\ 0, & if\ the\ project_i\ is\ not\ in\ the\ plan \end{cases}$$

$$Max\ \sum_{i=1}^{N} NPV_i \times x_i = Max \sum x_i \times \mu_i$$

Constrain:

$let\ j = 1,2 \cdots\cdots N$

Risk $Over_j = \begin{cases} 1 & if\ \sum x_i \times Capex_{ij} > B \\ 0 & otherwise \end{cases}$ this part is nonlinear and not the decision variable.

$$\frac{Over_j}{N} \leq \text{Max}\, Risk$$

$i \in (1,2,3,4, \ldots \ldots, \ 12)$ = project
$\sigma_j\ j = (1,2,3)$
$\sigma_i \cap \sigma_j = \emptyset$
$\sigma_1 \cup \sigma_2 \cup \sigma_3 = Projects$
$\sum x_i > 1$

Solution 1: Cash Reserve
Using a 95% budget limit as the benchmark, the expected value of total Capex should be less than the 95% budget limit. In the beta-PERT distribution table, the sum of the mean values of NPV multiplied by the corresponding x_i is taken as the maximization objective. This is calculated using the Simplex LP method in Excel. The result obtained is a **Total NPV of 1635.8533.**

Solution 2: Genetic Algorithm
First, convert the dynamic samples from Q2 into static samples, ensuring that the sample values are fixed and no longer subject to random changes.

Next, calculate the annual total Capex and the three-year total Capex by multiplying the static samples by the corresponding x_i. Then, evaluate whether each possible value exceeds the budget.

Using a 5% threshold to measure the estimated risk, ensure that the estimated risk is below 5% in the calculations.

Finally, use the Evolutionary method in Excel for calculations.

When using the default parameters, **the expected value of total NPV is 1620.38**. After adjusting the parameters, the **expected value of total NPV slightly increases to 1625.34.**

Solution 3: Integer Programming
First, convert the dynamic samples from Q2 into static samples, ensuring that the sample values are fixed and no longer subject to random changes.

Next, calculate the annual total Capex and the three-year total Capex by multiplying the static samples by the corresponding x_i. Then, evaluate whether each possible value exceeds the budget.

The difference in this approach is that it compares the values exceeding the budget with an upper bound, ensuring that the number of values exceeding the budget is less than the upper bound. This introduces two changing variables: one for which projects will be included in the final plan and another for which iterative project simulation data exceed the budget.

Finally, use the Simplex LP method in Excel for calculations.

However, it was found that regardless of using 90 sets of simulation iteration sample data or 50 sets of simulation iteration sample data for prediction, this scale of calculation exceeds the capabilities of Excel Solver. Therefore, Integer Programming is only suitable for handling smaller problems.

If maximizing the average total NPV is the deciding criterion, then Solution 1 is the best among the three solutions. **Total NPV is 1635.8533.**

Conclusion and Recommendations
Firstly, uncertainty is a common issue encountered in daily life and work. As seen in Q1, disregarding uncertainty yields theoretical values, which are useful for reference.

Secondly, since uncertainty is a common occurrence in daily life, using mathematical methods to generalize it provides values that are closer to reality. In this case, we use the beta-PERT distribution to generalize the possible value ranges for Capex and NPV. By expressing uncertainty through maximum, minimum, and most likely values, we simulate multiple possible scenarios and predict realistic outcomes through risk assessment.

Thirdly, combining uncertainty and simulation data provides values closer to what might actually occur. By evaluating three methods, we find that the results of the first two solutions are similar. However, the third method, Integer Programming, is not suitable for analyzing and computing more complex or large-scale problems.

Reference List:

Wayne L Winston, & S. Christian Albright (2017) Practical Management Science,

South West College ISE;