

24CGC053
Process Economics and Project Management

Semester 1 2024/25

In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Attempt **THREE** questions in total. Each question carries 25 marks.

Candidates should show full working for all calculations and derivations.

A table of the Normal distribution is provided at the end of the paper.

1. A major upgrade of a petrochemical plant is estimated to give an annual cost-saving of £400,000 for an outlay of £1 million.

(a) Derive the pay-back period and the Gross Return on Investment (GROI). [3 marks]

(b) On further enquiry, the contractors concede that these are 'most likely' figures and agree that pessimistically the capital estimate could be 70% higher or optimistically 10% lower. Similarly, they say that the annual cost-saving could be pessimistically 40% lower or optimistically only 10% higher.

As the project is being proposed for an existing plant already over 10 years old, its life is also uncertain. Most likely it will run for 4 years, but an optimistic estimate puts the life at 11 years, and a pessimistic estimate at 3 years.

The contractor generally uses a minimum acceptable Discounted Cash Flow rate of return (DCFRR) of 10% per annum in its calculations. Using this criterion, estimate the chances of the project's NPV exceeding zero (chances of success). [15 marks]

(c) Unfortunately, the client company uses a different investment criterion, which is that projects must achieve a gross return on investment of 30% p.a. (instead of the DCFRR criterion above).

(i) Show that these criteria can be considered consistent for a certain value of project life and evaluate this value of project life. [5 marks]

(ii) Determine if the two criteria are reasonably compatible with one another in the case of this project. [2 marks]

The differential equation $\frac{\partial}{\partial n}(1+i)^{-n} = -(1+i)^{-n} \ln(1+i)$ may be useful.

Where the symbols have their usual meaning.

A table of the Normal Distribution is attached at the end of the examination paper.

2. (a) Give an outline proof of the NPV equation below. Explain the assumptions made in the proof and define the meanings of all the symbols.

$$NPV = P \left(\frac{1 - (1+i)^{-n}}{i} \right) - C$$

[5 marks]

- (b) A project has a single capital outlay and constant annual profits. Derive an expression which relates the Gross Return on Investment (GROI) to the Minimum Acceptable Rate of Return (MARR). [5 marks]
- (c) For a plant life of 10 years and MARR of 20% p.a., determine the corresponding minimum acceptable GROI. [3 marks]
- (d) Table Q2 below gives the capital investment and net cash inflow for a basic plant design, Case 1, together with the additional investments and associated cost savings for each of four independent heat recovery proposals (Cases 2-5 in Table Q2). The plant life is 10 years, and the minimum acceptable Discounted Cash Flow (DCF) rate of return is 20% p.a. It can be assumed that funding is available for all options.
- (i) If it is possible to adopt any combinations of Cases 2 to 5 proposals, determine which investments should be made. Show how compatible results can be achieved using both NPV and GROI methods. [6 marks]
- (ii) Estimate the DCF rate of return for the entire project (Cases 1 to 5 combined). [6 marks]

Table Q2. Basic information of project proposals

	CAPITAL (C)	NET CASH INFLOWS (P) p.a.
Case 1	£310,000	£88,200
Case 2	£25,000	£9,200
Case 3	£19,000	£4,600
Case 4	£16,000	£2,200
Case 5	£14,000	£2,900

3. The source temperatures, target temperatures and heat capacity flowrates of four process streams in a chemical plant are shown in Table Q3.

Table Q3. Source temperatures, target temperatures and stream heat capacities of process streams.

Stream	Source temperature (°C)	Target temperature (°C)	Heat capacity flowrates (kW °C ⁻¹)
1 Hot	150	70	2
2 Hot	120	30	3
3 Cold	20	140	1.5
4 Cold	60	120	4

- (a) Calculate the heat duties for each stream and determine the overall heating and cooling duties for the process. [4 marks]
- (b) Construct a problem table to determine the hot and cold utility requirements and the temperature of the pinch. The minimum temperature difference, ΔT_{\min} is 10°C. [12 marks]
- (c) Discuss the significance of the pinch. [4 marks]
- (d) Construct a fully labelled grid diagram for the process by clearly indicating the location of the pinch, temperature limits for each stream and respective heat capacity flowrates. [5 marks]

4. Table Q4 shows the necessary activities to replace the catalyst and clean a large packed-bed chemical reactor assembly. The assembly consists of 100 tubes (2.5 cm in diameter) which are filled with granular catalyst and arranged inside a large shell with end boxes. The cooling fluid flows through the shell to maintain a constant operating temperature of the catalyst bed. The optimistic, most likely and pessimistic times of each activity are also reported in Table Q4.

Table Q4 Project description, times and resources.

Activity code	Activity description	Optimistic time (hours)	Most likely time (hours)	Pessimistic time (hours)
A	Purge liquid from tubes, flush, seal off, and disconnect reactor	2	3	7
B	Lift reactor clear, remove end-boxes and reactor tube bundle	1	1.5	2
C	Clean connecting pipework	1	1.5	2
D	Clean end boxes	1.5	2	4
E	Clean shell	2	3	4
F	Remove catalyst and clean inside tubes manually and by steam blast	3	4	8
G	Clean outside tubes	6	8	13
H	Inspect shell and end-boxes once they have been cleaned	0.5	0.7	1.2
I	Inspect inside tubes	0.6	0.7	1.4
J	Inspect outside tubes	1	1.2	1.7
K	Inspect connecting pipework once it has been cleaned	1	1.4	1.8
L	Reassemble, pack catalyst inside tube remount and reconnect exchanger	12	15	24
M	Remove seals, flush, purge and test	2	2.5	6

Notes:

- Activity B should be completed before cleaning. Cleaning should be done before inspecting. Inspecting should be done before reassembly.
- The cleaning operations (activities C to G) can run simultaneously except that the outside of the tubes must be cleaned before the inside.
- Activities I and J can be undertaken simultaneously but can only be done after both the inside and outside of the tubes have been cleaned.

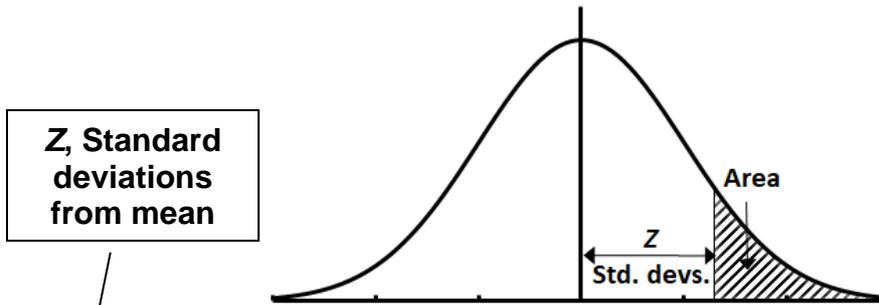
Continued/...

Q4 Continued/...

- (a) Draw an activity-on-arrow diagram for the project labelling each node with progressive numbers and each arrow with the job code given and its expected activity time. Determine the Earliest Event Time (EET) and the Latest Event Time (LET) for each activity and report these in each node. Determine the total project time. [12 marks]
- (b) Find the critical path and determine the time to have 95% certainty to complete the project. [8 marks]
- (c) Determine the free float of each activity and list the activities that have flexibility with regards to their starting time. [5 marks]

A table of the Normal Distribution is attached at the end of the examination paper.

NORMAL DISTRIBUTION



	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.50000	.49601	.49202	.48803	.48405	.48006	.47608	.47210	.46812	.46414
0.1	.46017	.45621	.45224	.44828	.44433	.44038	.43644	.43251	.42858	.42466
0.2	.42074	.41683	.41294	.40905	.40517	.40129	.49743	.49358	.48974	.48591
0.3	.38209	.37828	.37448	.37070	.36693	.36317	.35942	.35569	.35197	.34827
0.4	.34458	.34010	.33724	.33350	.32997	.32636	.32276	.31918	.31561	.31207
0.5	.30854	.30503	.30153	.29806	.29460	.29116	.28774	.28434	.28096	.27760
0.6	.27425	.27093	.26763	.26435	.26109	.25785	.25463	.25143	.24824	.24510
0.7	.24196	.23885	.23576	.23270	.22965	.22663	.22363	.22065	.21760	.21476
0.8	.21186	.20897	.20611	.20327	.20045	.19766	.19489	.19215	.18943	.18673
0.9	.18406	.18141	.17879	.17619	.17361	.17106	.16853	.16602	.16354	.16109
1.0	.15866	.15625	.15386	.15151	.14917	.14686	.14457	.14231	.14117	.13786
1.1	.13567	.13350	.13136	.12924	.12714	.12507	.12302	.12100	.11900	.11702
1.2	.11507	.11314	.11123	.10935	.10749	.10565	.10383	.10204	.10027	.19853
1.3	.09680	.09510	.09342	.09176	.09012	.08851	.08691	.08534	.08379	.08226
1.4	.08076	.07927	.07780	.07636	.07503	.07353	.07214	.07078	.06944	.06811
1.5	.06681	.06652	.06426	.06301	.06178	.06057	.05938	.05821	.05705	.05592
1.6	.05480	.05370	.05262	.05155	.05050	.04947	.04846	.04756	.04648	.04551
1.7	.04457	.04363	.04272	.04182	.04093	.04006	.03920	.03836	.03754	.03673
1.8	.03593	.03515	.03438	.03363	.03288	.03216	.03144	.03074	.03005	.02938
1.9	.02872	.02807	.02743	.02680	.02619	.02559	.02500	.02442	.02385	.02330
2.0	.02275	.02222	.02169	.02118	.02068	.02018	.01970	.01923	.01876	.01831
2.1	.01786	.01743	.01700	.01659	.01618	.01578	.01539	.01500	.01463	.01426
2.2	.01390	.01355	.01321	.01287	.01255	.01222	.01191	.01160	.01130	.01101
2.3	.01072	.01044	.01017	.00990	.00964	.00939	.00914	.00889	.00866	.00842
2.4	.00820	.00798	.00776	.00755	.00734	.00714	.00695	.00676	.00657	.00639
2.5	.00621	.00604	.00587	.00570	.00554	.00539	.00523	.00508	.00494	.00480
2.6	.00466	.00453	.00440	.00427	.00415	.00402	.00391	.00379	.00368	.00357
2.7	.00347	.00336	.00326	.00317	.00307	.00298	.00289	.00281	.00272	.00264
2.8	.00256	.00248	.00241	.00233	.00226	.00219	.00212	.00205	.00199	.00193
2.9	.00187	.00181	.00175	.00169	.00164	.00159	.00154	.00149	.00144	.00139
3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00103	.00100
3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.00071
3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.00050
3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.00035
3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.00024
3.5	.00023	.00022	.00022	.00020	.00020	.00019	.00019	.00018	.00017	.00017
3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.00011
3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00009	.00008	.00008	.00008
3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.00005
3.9	.00005	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00003	.00003
4.0	.00003	.00003	.00003	.00003	.00003	.00003	.00002	.00002	.00002	.00002
4.1	.00002	.00002	.00002	.00002	.00002	.00002	.00002	.00002	.00002	.00002
4.2	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001
4.3	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001
4.4	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001	.00001

END OF PAPER

Mrs M Kreft, Dr J Wagner, Dr H Yang