Answer for the Individual Assignment of the Maintainability Module

1. There are four major subsystems in one system design. Their failure rates and mean corrective maintenance times are as follows:

Subsystem i	λ_i (per days)	$M_{CT\,i}$ (days)
1	1/2000	1
2	1/1000	2
3	1/800	0.5
4	1/5000	1

Mean preventive maintenance time $\bar{M}_{pt} = 0.5$ hours at the frequency of *fpt*=1/600 per hour. Each maintenance task, no matter corrective or preventive, on average takes 0.4 hours of logistics delay time and 0.3 hours of administration delay time. Please calculate the mean maintenance downtime for one maintenance task.

ANSWER:

$$\overline{MCT} = \frac{\sum_{i=1}^{4} \lambda_i \bar{M}ct_i}{\sum_{i=1}^{4} \lambda_i} = \frac{\frac{1}{2000} + \frac{2}{1000} + \frac{0.5}{800} + \frac{1}{5000}}{\frac{1}{2000} + \frac{1}{1000} + \frac{1}{800} + \frac{1}{5000}} = 1.127 \text{ days}$$

$$\lambda = \sum_{i=1}^{4} \lambda_i = \frac{1}{2000} + \frac{1}{1000} + \frac{1}{800} + \frac{1}{5000} = 0.00295 \text{ per day}$$

$$\bar{M} = \frac{\lambda \overline{M_{CT}} + fpt \overline{M_{pt}}}{\lambda + fpt} = \frac{(0.00295)(1.1275) + \frac{0.5/24}{600/24}}{0.00295 + \frac{24}{600}} = 0.00416 \text{ days} = 2.324 \text{ hours}$$

MDT=$\bar{M}$+ LDT + ADT=2.324+0.4+0.3=3.024 hours.

Please be careful at the **units** (days vs. hours)

2. Given the following data, calculate the achieved availability
   a. $\bar{M}_{ct}$=0.5 hour
   b. $MTBM_u$=2 hours
   c. $\bar{M}_{pt}$=2 hours
   d. $MTBM_s$=1,000 hours

ANSWER:
First, the MTBM must be calculated:

$$\frac{1}{MTBM} = \frac{1}{MTBM_u} + \frac{1}{MTBM_s} = \frac{1}{2} + \frac{1}{1000} = 0.501$$

$$MTBM = \frac{1}{0.501} = 1.996$$

The mean time between maintenance is 1.996 hours. Now, the mean active maintenance time must be determined:

$$\lambda = \frac{1}{MTBM_u} = \frac{1}{2}$$

$$f_{pt} = \frac{1}{1000}$$

$$\bar{M} = \frac{\lambda(\bar{M}_{ct}) + f_{pt}(\bar{M}_{pt})}{\lambda + f_{pt}} = \frac{\frac{1}{2}(0.5) + \frac{1}{1000}(2)}{\frac{1}{2} + \frac{1}{1000}}$$

$$\bar{M} = 0.5030$$

The mean active maintenance time is 0.503 of a day. The achieved availability can now be calculated:

$$A_a = \frac{MTBM}{MTBM + \bar{M}} = \frac{1.996}{1.996 + 0.5030}$$

$$A_a = 0.7987$$

From the given information, the achieved availability is 79.87%.

3. The requirement $\bar{M}_{ct}$ for an equipment item is 65 minutes. A maintainability demonstration is accomplished and yields the results given in the table for 50 tasks demonstrated (Task time in minutes).

39	57	70	51	74	63	66	42	85	75
42	43	54	65	47	40	53	32	50	73
64	82	36	63	68	70	52	48	86	36
74	67	71	96	45	58	82	32	56	58
92	91	75	74	67	73	49	62	64	62

   a. Did the equipment pass the maintainability demonstration?
   b. In reality, after which task can the conclusion be drawn?

   The acceptance and rejection table (Demonstration 1, Plan A in Figure 13.23 in the Textbook) is as follows.

ANSWER:

a.

No the equipment did not pass the demonstration. The acceptance/rejection table is given below. By tallying the number of measured maintenance times greater than or equal to 65 minutes, the equipment failed the maintainability demonstration at task 22 when the cumulative number of exceptions exceeded the rejection value of 10. Task 22 is highlighted in red in the table.

Acceptance/Rejection Table

Maint Task No.	Measured Task Time	Cumulative Tasks >Mct	Accept /When Cum ≤	Reject /When Cum >
1	39	0	-	-
2	57	0	-	-
3	70	1	-	-
4	51	1	-	-
5	74	2	-	5
6	63	3	-	6
7	66	3	-	6
8	42	3	-	6
9	85	4	-	7
10	75	5	-	7
11	42	5	-	7
12	43	6	0	7
13	54	6	0	8
14	65	6	0	8
15	47	7	1	8
16	40	7	1	9
17	53	7	1	9
18	32	7	1	9
19	50	8	2	9
20	73	9	2	10
21	64	10	2	10
22	82	11	3	10
23	36	11	3	11
24	63	11	3	11

b.

The demonstration could have been stopped after task 22 because that is when the rejection criterion was met.

Group Assignment

a. Please read the document of *Maintainability Issues in the Disaster of Space Shuttle "Columbia"* as the file of "Maintainability_Columbia_Case.pdf" in the reading material.
b. Please prepare a report to discuss the importance of maintainability in system design and operations. Specifically, please discuss whether maintainability was well addressed in the original design of Columbia and during its operations. The discussion should include three maintainability measures mentioned in the lecture notes such as maintenance times, maintenance frequency factors, and maintenance cost.

Some pointers expected in students' report

- The maintenance time, cost, and frequency of Space Shuttles were significantly underestimated during their original design.
- The life-cycle maintainability issues have not been well considered in the design phase, especially maintainability for aging systems. When a system ages, it typically requires more maintenance efforts regarding time, cost, and frequency.
- NASA and contractors cannot estimate/predict the duration and content of maintenance tasks for Space Shuttles. The large variability often causes trouble in staying within schedules.
- The estimation/prediction of the duration and frequency of maintenance tasks should be considered during the design phase and be consistent to the availability requirement.
- The estimation/prediction of the duration and frequency of maintenance tasks may be updated during operations. Operations schedules should incorporate the maintenance needs.
- The practice of the Space Shuttle program is against the decision process of RCM described in slide 27. In reality, the maintenance requirement along with the safety requirement may conflict with the cost requirement and schedule requirement. The safety, especially for manned missions, should not by compromised by the cost or schedule in maintenance.
- In order to have good maintainability, maintenance of maintenance equipment and infrastructure, along with spare part availability, should be considered from early design.