Crib for 4C4 Design Methods 2022/2023

Version: POK/3

Question 1

a)

This question follows the example given in the notes.

The filling equipment is able to dispense the required volume of gel to within 0.5 %, while the weight of the bottle is given ± 0.5 g, and 2σ is assumed from minimum to maximum. Subscripts: G = gel, B = bottle, T = total, M = measured

$\mu_G = 500$ g, $\sigma_G = 2.5$ g
$\mu_B = 50$ g, $\sigma_B = 0.5$ g

The total weight of the filled bottle is given by: $W_T = W_G + W_B$, and using $y = a_1x_1 + a_2x_2$:

$\mu_T = \mu_G + \mu_B = 500$ g
$\sigma_T^2 = \sigma_G^2 + \sigma_B^2 = 6.5$ g
$\sigma_T = 2.55$ g

The weighing equipment is accurate to within 1 %. The measured weight of the filled bottle is given by: $W_M = W_T \times W_S$, and using $y = x_1x_2$:

$\mu_M = \mu_T\mu_S = 550 \times 1 = 550$ g
$\sigma_M^2 = \mu_T^2\sigma_S^2 + \mu_S^2\sigma_T^2 = (550)^2(0.01)^2 + (1)^2(2.55)^2 = 36.75$ g
$\sigma_M = 6.062$ g

The filled bottles is to weigh 550 g ± 5 g. So the probability of rejection is given by:

$P(W_M < 545) + P(W_M < 555)$, where
$P(W_M < 545) = P(W_M < 555)$ due to symmetry.

Use the standard tables substitute:

$$z = \frac{W_M - \mu_M}{\sigma_M} = \frac{545 - 550}{6.062} = -0.825$$

$P(W_M < 545) = 1 - P(z = 0.825) = 1 - 0.795 = 0.205$, from tables

Therefore, the probability of a reject bottle $= 2 \times 0.205 = 41\%$

b)

This question requires the student to think about the sensitivity of the parameters in the calculations above, and comment on the accuracy and cost of weighing and filling equipment industry.

To reduce the rejection rate, one might:

Improve the accuracy of the filling equipment The filling equipment is able to dispense the required volume of gel to within 0.5 %. This gives a tolerance of ± 2.5 g for the 500 g of shower gel.

Reducing this tolerance is possible, but will require replacing the filling equipment with a more expensive new system. From the calculation above, doubling the accuracy (or halving the tolerance) of the filling equipment reduces the overall rejection rate by less than 10%. The cost of the new filling equipment (expensive) would need to be weighed against the lost product which results from overfilling the bottles.

Improve the accuracy of the weighing equipment The weighing equipment is accurate to within 1 %. This gives a tolerance of ± 2.55 g for the 550 g filled bottle.

The accuracy of the scales could be easily be improved. Weighing scales with much higher accuracy, say ± 0.1 g over 500 g are not expensive. From the calculation above, doubling the accuracy (or having the tolerance) of the weigh scales reduces the overall rejection rate by more than 50%, so this seems a good option. The cost of the new weighing scales would need to be weighed against the lost product which results from overfilling the bottles.

Reduce the rejection tolerance The filled bottles are to weigh 550 g ± 5 g.

This tolerance has two purposes: to avoid under-filling the bottle (¡500 g of shower gel) and cheating the customer; to avoid overfilling the bottles which results in lost shower gel and additional cost. However, if the overfilling tolerance is relaxed, the probability of rejection is immediately halved (i.e. the symmetry removed). Deliberately overfilling the bottles to say 515g of shower gel, would reduce the probability of rejection due to under-filling to less than 1%. This appears to be a viable option. If the shower gel from the rejected bottles can not be recovered then 205 g (41%) plus the bottle is lost for each 500 g bottle, versus 15 g + 5 g (1%) of shower gel with the tolerance changed.

c)

In Failure Mode and Effect Analysis (FMEA) components are taken in turn and the effects of failure considered in terms of safety and reliability. The output of the analysis is an action list specifying required design changes or further hazard analysis.

Consider the filling valve sub-system. Four possible failure modes and effects are shown in the table below. For each failure mode some possible actions are given to avoid the failure. Only the VALVE FAILS CLOSED and VALVE TIMING ERROR failures can be detected by weighing the bottle after filling.

No.	Failure Mode	Effect	Action
1	VALVE FAILS OPEN	Liquid overflows	Monitor valve opening Flow meter on liquid line
2	VALVE FAILS CLOSED	No liquid in bottle	Weigh bottle after filling Reject or refill bottle Monitor valve closing Flow meter on liquid line
3	VALVE TIMING ERROR	Incorrect volume of liquid in bottle	Weigh bottle after filling Reject bottle Monitor timing
4	VALVE SEAT WEAR	Product contamination	Sample testing Inspect valve regularly

Question 2

a)

Design a device that serves as a memory aid for people with amnesia.

b)

The overall function can be decomposed into function structures in several ways and individual solutions are judged on whether they correctly model the flow of signals and energy between necessary sub-functions to carry out the overall functions. One method to arrive at a set of function structures is as follows. Candidates are expected to draw the corresponding diagram.

The overall function is `Aid Memory`. It can be decomposed into `Take Photo`, `Transfer Photo` and `View Photos`.

`Take Photo` represents the wearable device and requires the subfunctions `Take Photo` requires the subfunctions `Provide Power`, `Sense Photo Opportunity`, `Capture Photo` and `Store Photo`. Energy flows from `Provide Power` to the remaining functions. `Sense Photo Opportunity` sends a *Photo Capture* signal to `Capture Photo`, which sends a *Photo* signal to `Store Photo`.

`View Photos` represents a device for later viewing of photos and it can be decomposed into `Browse Photos` and `View Photos`. There are at least two signals *Photo Selection* and *Return*. Further decomposition and associated signal analysis is possible.

Finally, there is a `Transfer Photo` subfunction which can be decomposed to `Send Photo` and `Receive Photo`, the former on the wearable device and the latter on the external device. There is a *Photo* signal between these subfunctions.

c)

Candidates are expected to create a morphological chart, for example in the form of table, that maps five functions in (b) to three corresponding candidate function carriers, for instance, the following:

Function	**Function Carrier 1**	**Function Carrier 2**	**Function Carrier 3**
Provide Power	Built-in Lithium-Ion Battery	Replaceable Alkaline Battery	Replaceable Lithium Coin Cell Battery
Store Photo	Flash	EEPROM	Mechanical Drive
Sense Photo Opportunity	Timer	Visual Scene Change	Sensor Fusion
Capture Photo	Fish-eye	Macro	Standard
Transfer Photo	USB Cable	Flash Drive Interface	Wireless

d)

Examples of key criteria that would fit the five required by the question are the following:

1. Small form factor
2. Long battery life
3. High photo storage capacity
4. High detection accuracy for identifying opportunities for capturing photos
5. Low cost
6. High picture quality
7. Maximum coverage of visual scene
8. Easy way to transfer photos
9. Easy way to browse photos

e)

Using the morphological chart in (c) it is possible to generate concepts (combinations of function carriers) that can be qualitatively assessed by the criteria identified in (d). Optionally it is possible to create a weighting for each criterion and score each concept numerically based on its assessed fit. However, this is not expected. The important aspect is that a concept is a selection of function carriers that are motivated against the identified criteria.

An example of a concept is the following:

A life-logger that uses a built-in Lithium-Ion battery as it has the best power consumption (Long battery life) and avoids the problem of providing a mechanism for user replacement of battery (Small form factor). The device will use Flash as it costs much less than EEPROM (Low cost) and is more reliable than a mechanical drive, which both consumes more power (*not* Low cost) and requires a larger device (*not* Small form factor). The device will use sensor fusion, say a combination of a timer and detecting a visual change, to maximise the probability of capturing unique photos (High detection accuracy for identifying opportunities for capturing photos) and will at the same time avoid needlessly polling sensors by the use of a timer (Long battery life). The camera will use a fish-eye lens to maximise the capture of the visual scene (Maximum coverage of visual scene). The device will use a wireless solution, say Bluetooth, to transfer photos easily between the device and a laptop/workstation (Easy way to browse photos).

Question 3

a)

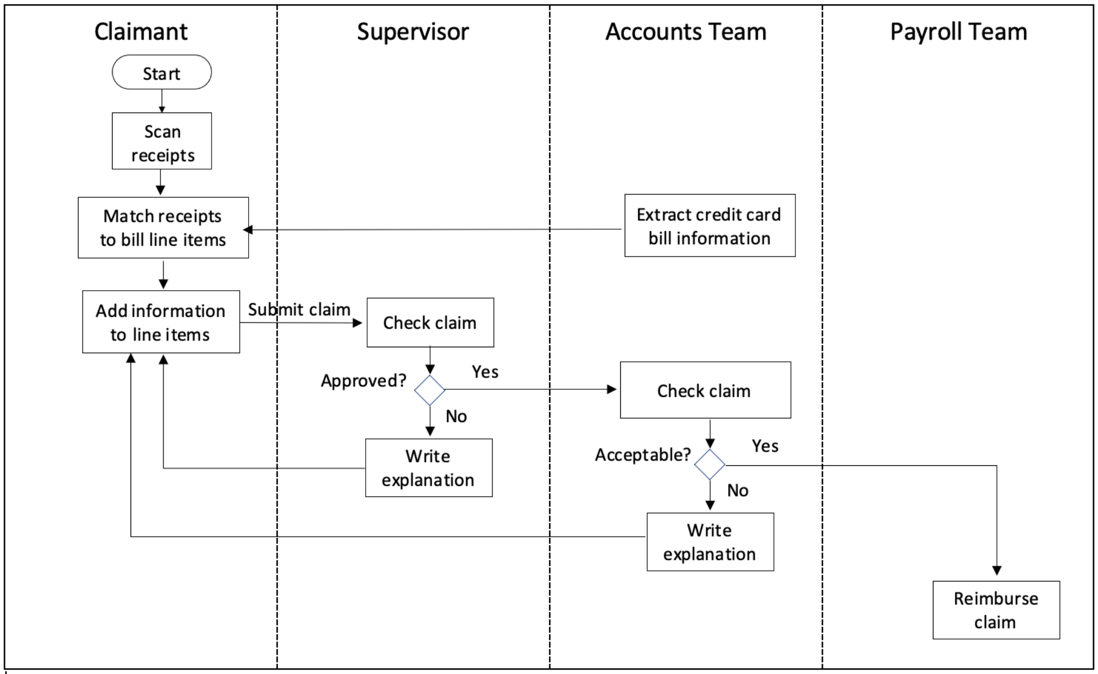
Design a system for collecting, approving and reimbursing expense claims.

b)

A flow diagram represents activities occurring in sequence or in parallel as key steps (nodes) and the conditions for moving between them (links). A swim-lane flow diagram also groups the activities into columns, according to the person who undertakes the activity.

The swim-lane flow diagram for a typical expense claim can take different forms. It should include the key aspects of the activities listed, with some simplification of the text permitted. The decision points for approval by the Supervisor and acceptance by the Accounts Team should be represented as diamonds, with the return loops back to the Claimant for unapproved or unacceptable expense claims.

An example is shown below:



c)

The MDM (Multiple-Domain Matrix) should include three matrices:

- an activity-based Dependency Structure Matrix (DSM)
- a people-based Dependency Structure Matrix (DSM)
- a Domain Mapping Matrix (DMM) linking the activities to the people, or people to activities (note only one DMM is required as they are reflections of each other).

The activity-based DSM should be partitioned so that it contains a few feedback marks as possible, resulting in a mostly lower triangular form. However, the return loops for unapproved or unacceptable expense claims cannot be brought to the lower triangle. A useful simplification is to combine the activities ”Add supporting information” and ”Assign job number”, giving two return loops rather than four.

The people-based DSM and the DMM are created from the text based on who performs the activities and in what order they are performed. The people-based DSM should include the return loop interactions.

An example is shown below:

	Scan receipts	Extract bill info	Match receipts to line items	Add info and job number	Check claim (approval)	Check claim (acceptance)	Reimburse claim	Claimant	Supervisor	Accounts Team	Payroll Team
Scan receipts											
Extract bill info											
Match receipts to line items	X	X									
Add info and job number			X		X	X					
Check claim (approval)				X							
Check claim (acceptance)					X						
Reimburse claim						X					
Claimant	X		X	X					X	X	
Supervisor					X			X			
Accounts Team		X				X			X		
Payroll Team							X			X	

d)

The return loops for unapproved or unacceptable expense claims create the potential for rework in the expense claim system. The activity-based DSM also shows this potential for rework as marks above the lower triangle which cannot be partitioned. The increase in processing time for each claim (rework) depends on the two factors:

- Quality (q) = work really done / work being done
- Rework discovery time (t) = time to discover / original project design time

For the new paperless expense claim process, either the quality has decreased, due to the Claimant providing incorrect supporting information or assigning the wrong job number, or the discovery time has increase, due to delays in the Supervisor or Accounts Team checking the expense claims.

The quality of the Claimant's expense claims can be improved through implementing a formal Verification process. Verification is defined as *ensuring that outputs for a specific device or activity meet particular input requirements*. This requires careful specification of the requirements (documentation and training of the Claimant) which the expense claims will be verified against (by the Supervisor and the Accounts Team).

The rework discover time can be reduced, by minimising any time delays in checking the expense claim, by the Supervisor or the Accounts Team.

Question 4

a)(i)

As the failure rate is constant the hazard function is λ and $R(t) = e^{-\lambda t}$. Further, $\lambda = 1/MTBF = 0.00002$.

Therefore, the reliability R_c of an individual component at t is $R_c = R(t) = e^{-\lambda t} = e^{-0.00002 \cdot 24 \cdot 365 \cdot 3} \approx 0.59$.

For the series system it is sufficient a single component fails for the system to fail. Thus, the probability of failure for the series system is $P_{series} = 1 - R_{series} = 1 - R_c^n = 1 - 0.59^n$.

For the parallel system, all components must fail for the system to fail. Thus, the probability of failure for the parallel system is $P_{parallel} = (1 - R_c)^n = (1 - 0.59)^n = 0.41^n$.

a)(ii)

Value is the ratio of function to cost. As the denominator is unity for both systems the value is the redundancy provided.

$R_{parallel} = 1 - P_{parallel} = 1 - 0.41^3 \approx 0.931$.

$R_{series} = 1 - P_{series} = 1 - (1 - 0.59^3) \approx 0.205$.

The gain in value is approximately 454%.

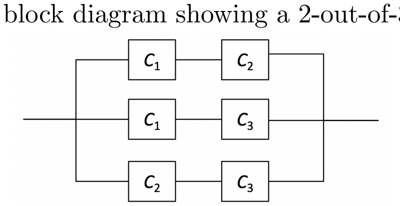
b)(i)

When $k = n$ this is a series system, thus $P_{series} = 1 - R_c^n$.

When $k = 1$ this is a parallel system, thus $P_{parallel} = (1 - R_c)^n$.

b)(ii)

A block diagram showing a 2-out-of-3 redundancy system at a function level may look as follows:



The structure function is $y(\mathbf{x}) = 1–(1–x_1x_2)(1–x_1x_3)(1–x_2x_3)$.

b)(iii)

We can rewrite the structure function in (b)(ii) as $y(\mathbf{x}) = x_1x_2 + x_1x_3 + x_2x_3 - 2x_1x_2x_3$.

This yields the following expression for the system reliability $R_{kn} = R_1R_2 + R_1R_3 + R_2R_3 - 2R_1R_2R_3$, where R_i is an individual component reliability.

Noting all that components have identical reliabilities, and thus $R_i = R_c$, the system reliability is therefore $R_{kn} = 3R_c^2 - 2R_c^3$.

Therefore $R_{kn} = 3 \cdot 0.59^2 - 2 \cdot 0.59^3 \approx 0.634$.

The gain in value compared to the series system in (a)(ii) is approximately 309%, which is less than the gain in value provided by the parallel system but is nonetheless still substantial.

The 2-out-of-3 system achieves a middle ground in redundancy on a continuum between an all-series and all-parallel system. If an all-parallel system is infeasible due to cost or technical constrains then a k-out-of-n system provides substantial additional redundancy compared to an all-series system.

c)

Three passes (six months) are required:

Pass	Work Really Done	Required Rework
1	90%	10%
2	99%	1%
3	99.9%	0.1%