# Crib for 4C4 Design Methods 2022

Version: JMC/5

## Question 1 - Glasses with internal camera

### a) marks 10%

The overall function is of the form `Manage Mobile Photography` (many possible formulations are possible). Importantly it is not merely `Take Photograph`, as this is a subfunction.

There are four main subfunctions and they are: `Take Photo`, `Browse Photos`, `Filter Photo` and `Delete Photo` and `Share Photo`. Several possible formulations are possible.

### b) marks 30%

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 between necessary subfunctions to carry out the overall function. One method to arrive at a set of function structures is as follows.

The overall function receives at least two signals: 1) a *User Input* signal; and 2) a *Photo* signal. In addition it has energy as input (power) and output (waste heat). It is possible to also decompose user input signals into there individual variants. The overall function can be decomposed into the following user-centred subfunctions: `Take Photo`, `Browse Photos`, `Filter Photo` and `Delete Photo` and `Share Photo`. In addition, at a minimum, the system requires a `Provide Power` subfunction, a `Connect Devices` subfunction, a `Disconnect Devices` subfunction and a `Transmit Information` (between devices) subfunction.

The subfunctions `Take Photo`, `Browse Photos`, `Filter Photo` and `Delete Photo` and `Share Photo` can then be further decomposed into their corresponding input and output functions (e.g. `Browse Photo Input` and `Browse Photo Output`, where the former senses user intent and the latter provides system feedback. All these subfunctions require power and receive two input signals (user intent and photo information) and a flow of two output signals (user feedback and transformed photo information; e.g. a photo is either shown, selected, filtered, deleted or shared).

In addition, the system is required to maintain a connection between the glasses and the smartwatch using the `Connect Devices`, `Disconnect Devices` and `Transmit Information` subfunctions. The exact function structure diagram will depend on the where visual output is displayed (on the glasses or the smartwatch). If the smartwatch is used merely as a touchpad then user action subfunctions, such as `Filter Photo`, only need to relay information between the glasses and the smartwatch using `Transmit Information` as an intermediary. Further details can be provided on how user input and system output is communicated across the design but this is not expected.

Several solutions are possible. Solutions are expected to be drawn as function structures with arrows clearly indicating energy and signal flows.

### c) marks 30%

A modular product architecture is created by decomposing the overall function into its subfunctions, attach any necessary flows of energy, materials and signals, and then cluster related functionality into modules. While the product architecture can vary, a typical *high-level* architecture would contain five main modules: 1) glasses; 2) integrated camera; and 3) smartwatch; 4) bespoke software for the glasses; and 5) bespoke software for the smartwatch. It is possible to continue modularisation by considering network connectivity, operating systems, etc. but it is also reasonable to assume the glasses, integrated camera and smartwatch are commodity components. A typical solution that assumes distributing the user interface across the glasses (output) and the smartwatch (input) will result in a modular product architecture with a clean separation of input and output across two modules.

## d) marks 30%

The system boundary encompasses at a minimum the glasses, the smartwatch and the user. Considering that `Take Photo` typically involves taking photographs of someone else than the user, it is also possible, and perhaps advisable, to also consider the environment or entity that is being photographed. Performance risks include connectivity disruptions between the glasses and the smartwatch and connectivity disruptions between the smartwatch and the external network. Other performance risks are high latency in user feedback and poor sensing of user intent and camera operational performance. User risks include accidentally deleting photographs, failing to connect the glasses with the smartwatch—or realise the connection has dropped—, not understanding the implications of deleting photographs, and either failing to realise the functionality available, failing to access it, or failing to understand the implications of the functionality available.

These risks can be mitigated using an active risk management strategy throughout development by understanding the scope the context, including the scope, the stakeholders/users and the risk evaluation basis and constraints. Thereafter a a process of risk assessment and risk analysis can be identified and carried out. This is followed by risk mitigation by—in the case of performance and user risks—in particular considering redesigns, but also (as appropriate) changes in documentation, such as the inclusion of warnings or clear descriptions. A risk matrix can be used to prioritise risks. The risk management plan is even evaluated and reviewed and referred to frequently during the design of the product.

## Examiners' comments

*This was a popular question. Candidates were generally able to identify the overall function, main subfunctions and function structure model, and subsequently able to modularise the function structure into a product architecture. The overall function was frequently convoluted and there was a tendency to omit several important subfunctions. Some candidates did not understand what a function structure is and provided a system diagram instead. Modularisations often omitted critical functionality, such as software or power, and frequently did not refer back to the function structures. Most candidates were able to identify sensible user and performance risks and propose some means of mitigating risk. However, candidates rarely proposed a coherent risk strategy that took all the identified risks into account.*

# Question 2 - Numeric keypad for medicine delivery machine

## a) marks 10%

A solution-neutral problem statement derivation can, for example, be of the form: "Design a system that allows administration of a medical dose" → "Design a system that allows safe administration of a medical dose" → "Design a system that allows safe administration of a medical dose using a keypad" → 'Design a system that allows safe quantification and administration of a medical dose using a keypad device."

## b) marks 10%

The overall function is to safely administer a set dose: `Administer Set Dose` (alternative formulations are possible and acceptable). The system boundary involves 1) a nurse; 2) an input device; 3) a medical device performing the actual administration of the dose; and 4) a patient. The system boundary encompasses these four entities at a minimum.

## c) marks 30%

Several sources of human error are possible. Three prominent sources of human error are:

1. Input error: The operator typing the wrong key by mistake.
2. State error: The operator mistakenly being in the wrong programme state. For example, by typing `Administer Dose` before the correct dose has been set.
3. Dosage error: The operator inputting the wrong dose, or failing to realise the wrong dose has been inputted before administrating the dose.

## d) marks 30%

Answers may vary depending on the sources of human error identified in (c). For the sources of human error identified in (c) the following can be done:

Input error: input error can be minimised by providing feedback. For example, the keys can use a combination of audiovisual feedback to ensure the nurse is aware of how the system has interpreted the input. This can be done by, for example, trigger a background light on any typed key and reading out the label of the typed key to the operator.

State error: A state error happens when the operator believes they are in a different state compared to the system. The design in this question is problematic as it gives rise to several occasions when this can happen. For example, a nurse may attempt to input a dose after typing `Reset` before typing `Set Dose`. State errors can be minimised by either removing states (such as removing the requirement to type `Set Dose` before setting a dose) or by making the system state sequence visible to the operator. This can be done by, for example, including labelled LED indicators that that light up the current state. For example, if the nurse is in the "set dose" state then a "set dose" LED indicator can light up.

Dosage error: This can happen if the operator inputs an incorrect dose and fails to notice the error. It can be partially rectified by providing audiovisual feedback in the input process as indicated when mitigating input error. It can also be mitigated by adding a confirmation step after the nurse types `Administer Dose`.

## e) marks 20%

Verification means ensuring requirements are met. To verify the sources of human error have been mitigated they therefore first must be encoded as requirements. Once they are encoded as requirements an appropriate verification cross-reference matrix (VCRM) can be set up that, among other things, specifies the verification method and success criteria.

A VCRM consists of a row for each requirement, and each row has the following columns:

- Requirement ID (matching the requirements specification)
- Requirement (matching the requirements specification)
- Verification method (without precise method)
- Allocation (indicating the subset of components and modules affected)
- Success criteria

A verification method will refer to an inspection, demonstration, test or analysis protocol. Design changes proposed in (d) thus lead to new requirements that can be encoded into a VCRM with an appropriate verification method. For example, modifying the design to mitigate state errors by making the states visible by LEDs lead to a (high-level) requirement that the states are shown to the user, which can be be subsequently verified by inspection. Input error mitigation can be verified by demonstration and dosage error mitigation can be mitigated by either a demonstration or test.

Validation means ensuring the design is fit for purpose in its intended use context. Validation here suggests a user study with nurses in a hospital environment, ensuring the dosage administration protocol is followed precisely without error. A way to do this is to use a think-aloud cognitive walkthrough protocol. However, other validation approaches are possible including an observational study, a log study, a diary study or even a controlled A/B experiment comparing the previous design with the new design and thereby quantifying the risk reduction of the new design.

## Examiners' comments

*This was another popular question. Most candidates struggled to include the safety aspect in their solution-neutral problem statement. Most candidates proposed a system boundary that failed to include the operator. Most candidates could propose three potential errors but often these errors overlapped and did not cover the critical aspects of the design. However, in general candidates proposed sensible mitigation strategies for their proposed errors. Candidates were generally able to explain how to verify and validate their proposed mitigation strategies.*

# Question 3 - Global aluminium production system

## a) marks 10%

From the lecture notes: a *system* is a set of parts which, when combined, have qualities that are not present in any of the parts themselves, where those qualities are the emergent properties of the system. In complex systems, individual parts interact with each other and with the outside world in many ways. The relationships between the parts determine how the system behaves. Taking an holistic approach considers the interaction between different parts of the system, the environment it operates in and the tools and procedures needed to build and operate the system.

## b) marks 30%

Insights gained into the system behaviour, with examples, might include:

- the transformation of ore, to metal, to fabricated parts, to products, along specific product supply chains (horizontal flows). For example, electrical cable can be traced back along the supply chain through industrial equipment, cable/wire fabrication, wire drawing process, billet production, and remelting or electrolysis of alumina.
- the breakdown of material flows (metals, parts products) in each vertical slice, allowing the relative scale of flow to be compared and ranked for priority. For example, vehicles, industrial equipment, construction, and metal products make up roughly equal fractions of aluminium product end-uses, with cars (7.9 Mt) the largest single end-use.
- the material yield of different processes can be compared, on an absolute basis (scrap aluminium in tonnes) and percentage basis (the fraction of scrap aluminium over the process input). The scrap aluminium flows are grouped (by forming and fabrication scrap) and can be compared to end-of-life scrap flows.
- the relative scale of aluminium production from ore (electrolysis), and from scrap (remelting and refining) can easily be seen, with further insight into the scrap flows and processing. For example, most end-of-life scrap is processed in refiners (6.5Mt of 8.3Mt total) and requires significant dilution with high-purity aluminium from ore (7.1Mt) to balance the alloy concentrations in the mixed scrap.

## c) marks 20%

The overall yield is 55%, calculated as 45 Mt of end-use products, divided by 81.4 Mt of recast aluminium (= 29.8 + 17.2 + 4.7 + 27.0 + 2.7). This means nearly half of all liquid aluminium produced never makes it into an end-use product.

Options for improving the yield of casting, rolling, forming and fabrication processes might include:

- casting components which are closer in shape to the final product specifications
- switching casting process to twin roll which eliminates the scrap generate in the hot rolling step, when making cold rolled components.
- preferring extrusion and wire drawing processes, with have lower fractions of scrap generation, over cast and sheet/strip/foil processes.
- improving the alloy uniformity when casting to avoid unnecessary trimming of sheet/strip/foil products
- reducing the occurrence of out of specification materials and faulty products, and identifying faults early

## d) marks 20%

Two factors are important when considering rework:

- Quality (q) = work really done / work being done
- Rework discovery time (t) = time to discover rework / original project design time, which applies to delays in discovering out-of-specifcation materials or faulty products.

The quality factor is equivalent to the material yield described in (c). Scrap generated in the casting, rolling, forming and fabrication processes requires additional time and energy input to remelt and recast products again.

The rework discovery time is equivalent to the delays in the aluminium production system for discovering out-of-specification materials and faulty products. In addition, scrap which is generated further downstream from the casting processes, will be discovered later, resulting in time delays and increased energy input to correct.

The inefficiencies in the system results in scrap generation in the processes. which in turn increases the handling requirements and remelting energy required to recast the aluminium products. This type of recycling is unwanted and counterproductive and should be eliminated where possible.

## e) marks 20%

Answering this question involves thinking about the evolution of the global aluminium production system over time.

A shift towards electric vehicles will reduce demand for cast aluminium end-use products used in vehicles, impacting companies who make die, permanent mould and sand castings. However, a similar reduction in the generation of cast aluminium scrap, from engine blocks and gearboxes in the current stock of vehicles, will be delayed by the lifetime of the vehicles (approximately 15 years). Thus, when this end-of-life scrap does becomes available, there will no longer be demand for new cast aluminium in vehicles. If new cast aluminium product lines are not developed, there will be an excess of cast aluminium scrap in the market.

## Examiners' comments

*This was a new question on systems, which was less popular. Most students were able to define a system and describe the benefits of taking an holistic approach. Many students struggled to describe insights from the aluminium production diagram, with many failing to add examples. Various calculations of the production yield were given, despite the question specifically defining the ratio required. Options for improving the yield often lacked specificity. Many students described the effect of quality on rework (but not the discovery time) and could see that the considerable generation of scrap metal in the manufacturing processes was creating rework. To achieve full marks students had to link the scrap generation (rework) to the additional energy required to remelt the aluminium. Most students could see that introducing electric vehicles reduces demand for cast aluminium, but not all linked this to an oversupply of scrap cast aluminium, with no obvious uses. Overall, students who chose this question and answered all parts, achieved high marks.*

# Question 4 - Remote University campus

## a) marks 20%

From the lecture notes:

- Risk management is the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events.
- Risk analysis involves the systematic identification of hazards (potential sources of harm) and their risks, how likely they are to cause a problem and how severe it would be if they did.

Risk analysis forms a part of the wider process of risk management.

## b) marks 20%

Risks can come from uncertainty in financial markets, project failures, legal liabilities, credit risk, accidents, natural causes and disasters as well as deliberate attacks from an adversary. Risks should be spread across these categories, and might include:

- Not attracting sufficient students
- Not finding sufficient teaching staff to be seconded
- Failure to deliver high-quality course material
- Failure to obtain legal permission to operate in country
- Inability to collect fees from students
- Reputation risk to the host university
- Course pitched at the wrong level for students
- Failure to find suitable property for campus
- Fire damage to buildings
- Flood damage to buildings
- Financial embezzlement from staff
- Failure to establish campus within five years
- Terrorist attack on campus
- Health pandemic

## c) marks 30%

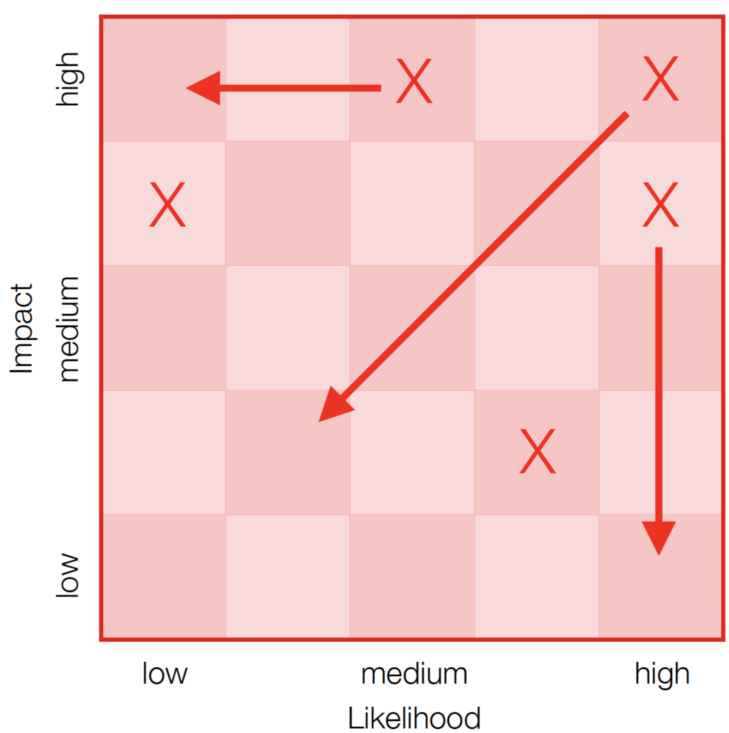
For all designed systems, there is a possibility that a system will not perform as expected, leading to some undesirable behaviour, where: Risk = Likelihood x Impact. Suitable scales for likelihood and impact might be:

| Score | Likelihood |
|---|---|
| 1 - low | Event likely to occur less than once in 10 years |
| 2 - | Event likely to occur once in 10 years |
| 3 - medium | Event likely to occur once in 3 years |
| 4 - | Event likely to occur once a year |
| 5 - high | Event likely to occur more than once a year |

| Score | Financial loss | Applications | No teachers | Establishment |
|---|---|---|---|---|
| 1 - low | <£100k | 90 plus | | |
| 2 - | £100k to £250k | 80 to 90 | | |
| 3 - medium | £250k to £500k | 50 to 80 | 0.5 course | Minor delays |
| 4 - | £500k to £1m | 20 to 50 | 1 course | Major delays |
| 5 - high | £1m plus | <20 | > 1 course | Unable to secure |

Students should assign likelihood and impact scores to each risk identified, and multiply the likelihood and impact to get final risk scores. The risks should be ranked according to these scores. The likelihood and impact scores chosen will be arbitrary, so marks are only given to the process. For example, Fire damage to buildings, might have a likelihood of 2– Event likely to occur once in 10 years and impact of 4– £500k to £1m, giving an overall risk score of 2 x 4 = 8.

The risk matrix will be of the form shown, with the ten risks plotted with a suitable key.



## d) marks 20%

The top five ranked risks will have mitigated actions to reduce the risk score. For example, Fire damage to buildings could be mitigated by installing a fire alarm system, reducing the impact to 1– <£100k, and the overall risk score to 2 x 1 = 2. The new risk scores can be added to the risk matrix in (c).

## e marks 10%

Alternative risk assessment tools might include:

- Structured What If Technique (SWIFT)
- Influence Diagram
- Event Tree
- Fault Tree

## Examiners' comments

*This question was less popular with students, but those who answered scored highly. Most students could define risk management and risk analysis and describe the differences to varying degrees. Fulls marks were given for listing 10 risks from across different areas (i.e. financial, teaching, infrastructure, political) with good detail. Several students failed to define descriptive scales for likelihood and impacts, but most could score and rank the risks and plot them on a risk matrix. Mitigation actions were marked for their credibility. Many students listed risk assessment tools which were inappropriate for the context (i.e. HAZOP).*