Crib for 4C4 Design Methods 2025/2026

Version: JMC/3

Question 1

(a) marks 20%

From the lecture notes, the potential benefits of QFD can be briefly summarised as follows:

- Cross functional teamwork
- Increases the sophistication of marketing inputs
- Focuses the mind on what you don't know
- Focuses on customer needs, not product features
- Prevents wild assumptions
- Ensures that all issues are considered, including customer requirements, technical characteristics and competitive products.

The potential drawbacks of QFD can be briefly summarised as follows:

- Can be exceedingly complex (e.g. a 10 x 10 matrix has 100 potential relationships)
- Can be difficult if the project is very complex, the project is poorly defined, there is too much detail
- Can be time consuming and involve too much administrative work
- Can become too 'analytical' and reduce fun
- Requires changes in how people work
- Produce a number, which can be treated as the 'right' answer

Full marks are available for five distinct points across both parts of the answer.

(b) marks 20%

Different possible Engineering Characteristics and Technical details can be specified, as long as they are distinct and related to the design of the vacuum cleaner . See Fig. 1 as an example.

(c) marks 20%

Priority scores are calculated by multiplying the Priority Ratings (given) by the Relationship types (Strong = 9, Moderate = 3, Weak =1), and summing these for each Engineering Characteristic. In the example in Fig. 1, the QFD suggests that "External device dimensions", with a score of 72, is the most important Engineering Characteristic , because it has two "strong relationship" marks in the relationships matrix, each associated with high priority rankings.

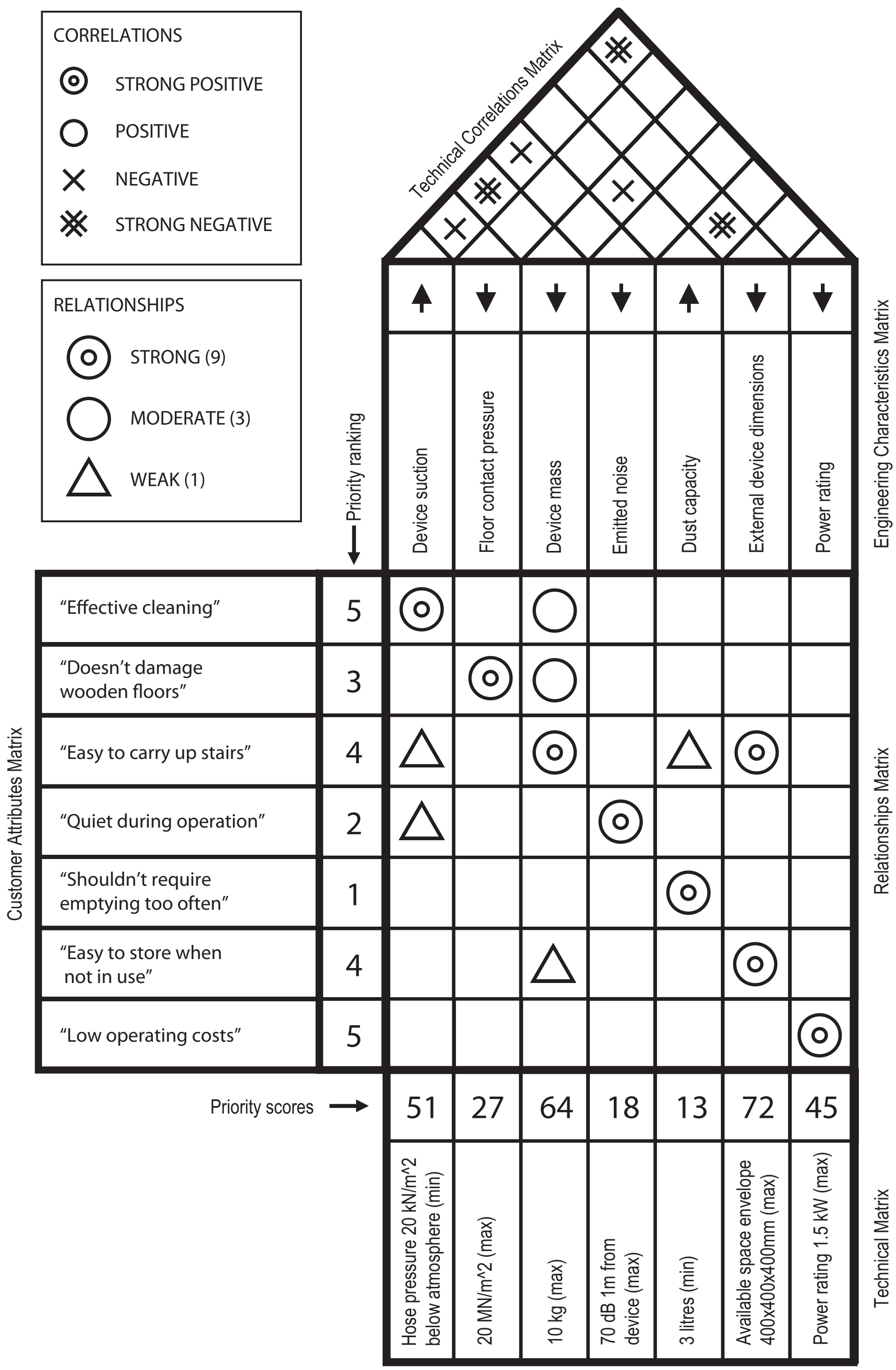

Figure 1: Completed QFD

(d) marks 20%

Various answers are possible, but it is plausible that the following correlations are strongly negative:

- increasing suction and decreasing mass (due to motor size)
- increasing capacity and decreasing external dimensions (due to housing the dust)
- increasing suction and decreasing operating costs (due to motor power)

All of these are likely to be important because they involve at least one high scoring engineering characteristic.

(e) marks 20%

Marks are available for identifying a contradiction and suggesting ways of resolving it. For example, using answer (ii) in (d) above, the contradiction between something being both big and small must be resolved. This could involve: designing the dust container to occupy voids left by other components; making the dust container collapsible and external to the device; compacting the dust prior to storage, using external dust storage that is not part of the device (e.g. plumbed into the house), etc. The use of creative methods such as the SCAMMPERR list is useful here.

Examiners' comments: This question was popular for IIB students, but not so for IIA students. The question was similar in topic and form to a previous question from 2013 and involved filling in a QFD (House of Quality) chart for a domestic vacuum cleaner. Those who did attempt the question scored well, with solid answers to part (a), good choice of Engineering Characteristics and corresponding Technical details (part b). Some students made simple errors in calculation the Priority Scores (part c) and about half of students didn't understand that negatively correlated characteristics required opposite direction arrows (part d/e).

Question 2

(a) marks 10%

A solution-neutral problem statement derivation can, for example, be of the form:

- Design a system that allows visually impaired people to navigate safely and independently
- Design a system that for safe mobility for blind people
- Design a device that allows visually impaired people to detect and avoid obstacles.

(b) marks 20%

Key functions might include:

1. `Detect obstacles` is a necessary function which is provided by the traditional guide cane.
2. `Detect surface texture changes` is a necessary function which is provided by the traditional guide cane.
3. `Alert user` is a necessary function to communicate to the user the presence of an obstacle or surface texture change.
4. `Suggest action` is necessary for the system to be able to communicate action to help the user avoid obstacles.

5. `Communicate device working` is necessary for the user to know the device is currently working.

Other functions are possible and acceptable as long as they are motivated and form the critical functions for addressing the solution-neutral problem statement in (a). The solution above can be thought of as the minimal acceptable solution.

(c) marks 20%

Function/Solution	Solution 1	Solution 2	Solution 3
Detect obstacles	Camera	Laser	Physical roller
Detect surface texture changes Camera	Laser	Physical roller	
Alert user	Haptic feedback	Audio via speaker	Audio via earphone
Suggest action	Haptic feedback	Audio via phone speaker	Audio via earphone
Communicate device working	Haptic feedback	Audio via phone speaker	Audio via earphone

(d) marks 40%

Different conceptual designs are possible. Sketches should be clearly annotated with the key functions translated to viable function carriers. The relative strengths and weaknesses of each design should be described separately, or in a table. Numerical scoring can optionally be used to assist the selection of a single preferred conceptual design.

Possible designs include:

One conceptual design choice might be to use a mobile phone, making use of the camera and a software app to detect obstacles and surface texture changes, and providing feedback via the phone speaker or through earphones. This solution reduces costs and the weight of the system. Vision detection software may require high levels of processing or a high-speed wireless connection, which may not always be available. The phone would need to be positioned with the camera facing forward, which might be challenging for a blind person. Perhaps a mount on a short cane might help the user. A secondary concern is also that stereo audio feedback would conflict with some users' desire to listen to music or use other navigation apps. This option makes use of modular design principles, providing flexibility abnd reduced cost.

An alternative conceptual design might be to design a standalone device, with a modified guide cane to include sensing equipment and haptic feedback. The cane might have a wheel system at the end to prevent the user having to carry a heavier cane, and a simple vision system to detect obstacles and surface texture changes. A speaker could provide feedback to the user, or the cane could connect to a mobile phone via bluetooth. The cane would need to have a battery which could be recharged. This design makes use of integral design principles, providing a more specialised solution which may be more robust.

(e) marks 20%

Requirements must be testable and traceable. There are many possible solutions and many sources are possible. The requirements should follow-on from the conceptual design in (c). It is also possible to include priorities but not necessary as the question asks about key requirements. Examples of requirements for the preferred concept include:

1. Mobile phone app must be operational within five seconds from initiating a connection from the app. Source: User research.

2. Mobile phone app must work on Apple and Android devices. Source: Market research.

3. Battery life must exceed 30 hours of use. Source: User research.
4. It must take a typical user less than 5 minutes to replace the battery. Source: Market research.
5. There must be a mechanism for signaling to the user that the camera is positioned correctly. Source: Usability guidelines.
6. There must be a mechanism for signaling to the user that the system is turned on. Source: Usability guidelines.
7. Mobile phone app must be able to work in parallel with other apps such as music or navigational guides. Source: User research.

Examiners' comments: This was the most popular question for IIA students, but not as popular for IIB students. The questions involved designing a new "smart guide cane" for people with visual impairment. Most students could write a solution-neutral problem statement (part a) and describe key functions (part b), with marks awarded for extracting the information from the specific design case. Most students created a Morphological chart (part c) with those describing three solutions or more, with distinct detailed options scoring well. The quality of sketches in part (d) varied greatly, with some good creative designs, but also many which were rushed and often not clearly annotated. Most students described testable and traceable requirements in part (e).

Question 3

(a) marks 10%

As the failure rate is constant the hazard function $\lambda = 1/MTBF = 0.0005$. The the reliability R_c of an individual component at t is $R_c = R(t) = e^{-\lambda t} = e^{-0.0005 \cdot 500} \approx 0.78$.

(b) marks 20%

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 $P_{series} = 1 - R_{series} = 1 - R_c^n = 1 - 0.78^5 = \approx 0.71$.

For the parallel system, all components must fail for the system to fail. Thus, the probability of failure for the parallel system is $P_{parallel} = (1 - R_c)^n = (1 - 0.78)^5 \approx 0.0005$.

(c) marks 20%

Value is the ratio of function to cost, where function is equal to the redundancy of the system.

$R_{parallel} = 1 - P_{parallel} = 1 - 0.0005 \approx 0.9995$.
$V_{parallel} = 0.9995/£20 = £0.050$

$R_{series} = 1 - P_{series} = 1 - 0.71 \approx 0.29$.
$V_{parallel} = 0.29/£10 = £0.029$

The gain in value is approximately 173%.

(d)(i) marks 10%

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

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

d)(ii) marks 30%

Using the complement method with $k = 2$ and $n = 5$, the system fails if $m = 0$ or $m = 1$ components work:

$$R_{kn} = 1 - \left(\binom{5}{0} p^0 (1-p)^{5-0} + \binom{5}{1} p^1 (1-p)^{5-1} \right)$$

Calculate the binomial coefficients $\binom{5}{0} = 1$, $\binom{5}{1} = 5$ and simplify the expression:

$$R_{kn} = 1 - \left(1 \cdot 1 \cdot (1-p)^5 + 5p(1-p)^4\right)$$

Factor out the common term $(1-p)^4$:

$$R_{kn} = 1 - (1-p)^4 \left[(1-p) + 5p\right]$$

This yields the following expression for the system reliability:

$$R_{kn} = 1 - (1-p)^4(1+4p)$$

Noting that $p = R_c \approx 0.78$ from (b), then $R_{kn} \approx 0.99$.

The value is $V_{parallel} = 0.99/£15 = £0.07$, or approximately 230% more gain than the series system from (b). This is more than the gain in value provided by both parallel system, at 170%.

The 2-out-of-5 system achieves a middle ground in redundancy on a continuum between an all-series and all-parallel system, when the cost is kept the same. But with varied costs, k-out-of-n can prove more effective.

(d)(iii) marks 10%

Fault trees use `OR` and `AND` gates to combine factors that contribute to the occurrence of an adverse or undesired event. There is similarity between parallel redundancy `OR` gates, and series redundancy and the `AND` gates. However, for fault trees the probability of a high-level event occurring is calculated by adding the probabilities of the contributing factors for `OR` gates and multiplying the probabilities for `AND` gates.

Examiners' comments: This question investigates the probabilities of failure, for series and parallel lighting systems. It was answered by most students in IIA, but few in IIB. Students scored well in the question, but with a wider range of marks. Most students were able to define the failure rate, hazard functions and reliabilities, for series and parallel (part a/b/c). Some students struggled in part (di) to define the probabilities of failure in relation to the reliabilities, confusing the relationship between them. In part (e), students struggled to explain how Fault Trees, with AND and OR gates, are related to series and parallel probabilities.

Question 4

(a) marks 30%

Risk management refers to the entire process of:

- hazard identification – identify what can go wrong
- risk estimation – assess the likelihood and severity of each hazard
- risk evaluation – decide whether risks are acceptable
- risk control – reduce any unacceptable risks to acceptable levels

- risk monitoring – checking that acceptable risk levels are maintained

A number of strategies were raised during the lectures, including:

- Reference to risk management as a means to drive the design process by identifying areas of high risk (show stoppers) which should be investigated in preference to low risk areas;
- The careful definition of the project requirements, with reference to active risk assessment to identify potential hazards, evaluate risks, and to define risk reduction priorities;
- Application of a formal approach to risk control during the development of the project, and across all three technology stages;
- Clear definition of the system performance metrics and associated risk monitoring methods;
- Reference to the rework model and the resulting need to maximise design quality and reduce delays in the discovery of rework;
- Use of the waterfall model as an example of a verification/validation led approach. Importance of validation of requirements as a precursor to design and the timely use of verification to identify problems early;
- Good communication and involvement of the stakeholders in the design and implementation.

(b) marks 30%

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. A prioritised list of risks, with actions, might look like:

Rank	Risk	Action
1	Failure to find skilled labour	Initiate a international recruitment drive
2	Inability to secure raw materials	Identify potential companies and negotiate early
3	Insufficient investment funds	Work with Government to underpin investment
4	Retraction of Government support	Sign long-term contract
5	Project delays	Set up efficient project management
6	Cost overruns	Manage possible rework and buy equipment early
7	High energy costs	Develop contracts with private renewable projects
8	Inability to secure technical patents	Don't start building until secured
9	Inability to find customers for the batteries	Undertake market research and develop partnerships with EV companies
10	Failure to obtain legal permission to operate in country	Secure this early as part of Government support

(c) marks 20%

HAZOP (Hazard and Operability Analysis) takes a process design which is assumed to be sound and systematically assesses the consequences and likely causes of a deviation from the intended performance of the system. Each process flow is analysed in turn against standard key words (e.g. turn none, more of, less of). Developed for the chemical industry, undertaken in groups, and requires expertise and good information. Requires detailed design and expertise, so would be useful for assessing risk for the operation of battery assembly processes

FMEA (Failure Mode and Effect Analysis) assesses the consequence of failure (total or partial) of a single component. Each component is analysed in turn against standard failure modes (e.g fails open, fails closed). Developed for the automotive industry, requires expertise and good information. Could be useful for understanding the risk of component failure, leading to failure of the battery units produced by the factor. Or for any control systems used on the battery factory.

FTA (Fault Tree Analysis) is a graphical device for identifying and analysing factors that contribute to the occurrence of an adverse or undesired event. Provides insight into the relevant causes of failure, and can be quantitative or qualitative. FTA is useful when 'mapping' and 'testing' causal links to a top event, which may be positive or negative. Good for understanding particular failure modes or undesired events. Useful for assessing the overall development risk for the design and build of the battery factory.

(d) marks 20%

From the lecture notes, the five principles for sustainable systems thinking are:

1. **Lifecycle thinking** considering the sustainability impacts at every lifecycle stage of the product production. Care should be taken to include the impacts of the electric vehicle and the battery factory which occur outside the companies immediate boundary, such as: the impacts from mining critical minerals, building the factory, disposing of the EVs and factory at end of life (i.e. recycling, incineration, landfill).

2. **Prioritising scale** The scale of substitution and impacts should be considered to assess the commercial viability and sustainability of the battery factory. For example, questions might be asked about: the size of the battery factory required to be commercially viable; the size of the battery market; the availability of sufficient critical minerals; how much waste will be produced and when.

3. **Accuracy and uncertainty** The company should take account of the uncertainty in both the activities and the emissions factors for these activities. Care should be taken when using lifecycle assessment numbers from databases, to decide whether these numbers are appropriate for use, or whether primary data should be collected. The is still much uncertainty around the future potential for EVs to reduce national emissions.

4. **Setting boundaries + allocating impacts** Care should be taken when comparing impacts between the existing technologies and new technologies, to ensure an appropriate boundary is chosen which reflects the major areas of impact and accounts for the differences in the products. For example, EVs are often claimed to be zero-emissions, however, the emissions required to build and disposal of EVs are not trivial. Additionally, the cost and impacts of building grid transmission and incorporating energy storage into the grid are not trivial. When preparing the sustainability impact assessment, the company should ensure that the impact grouping are mutually exclusive and collectively exhaustive, to avoid double counting or excessive truncation in the resulting impact assessment.

5. **Metrics and weighting** If a multi-criteria impact assessment is used, which compares the product across several impact categories, for example using a mix of environmental, social

and economic indicators, care should be taken to ensure the weighting of the indicators does not bias one of the product systems. Assessments should be measured using appropriate metrics, which do not obscure the real impacts. Here, the goal is to support net-zero targets, but it should be made clear how the battery factory also supports other goals such as automotive industry competitiveness, supply chain security, and economic growth priorities.

Marks are given for discussing at least three of the five principles for sustainable systems thinking.

Examiners' comments: This question on the risk management for a battery factor was popular for IIB students but less so for IIA students, with the marks scored by IIA students much lower than for other questions. Students struggled in some cases to describe elements of good risk management, despite this being a common question in the previous Tripos exams (part a). Most were able to detail 10 risks, with good range, rationale and mitigating actions (part b). Students gave average descriptions of HAZOP, FMEA and FTA, and but some struggled to connect these to the specific case (part c). Part (d) was answered better, with interesting sustainability ideas being proposed.