Chapter 2

1. What is engineering design?

Solution:

Engineering design involves the concerted efforts of designers and engineering managers to realize a profitable design that meets all the customer requirements.

2. Who is central to engineering design? When did this change in outlook towards design take place?

Solution:

A decision maker is central to engineering design. This gradual change in outlook took place in the late 1980s and well into the 1990s.

3. What is the role of decision analysis in design?

Solution:

Decision analysis is a normative field that helps determine the best course of action given the preferences of the designer. Consequently it is an integral part of a design process which is nothing but a sequence of decisions.

4. Identify the role of feasibility analysis in early stages of design.

Solution:

In the initial phases of design, there is significant uncertainty regarding the performance of the candidate designs. For example, one only has a rough idea of the cost of manufacture and profit margin. Many times even probability distributions of these need to be assessed from limited information. Feasibility analysis uses concepts like expected profit or dominance (deterministic or stochastic) to determine which designs are worth pursuing further.

5. While performing initial feasibility analysis it was assessed that two designs, A and B, have normal payoff distributions with {mean, standard deviation} of {4 million, 1 million} and {5 million, 2 million} respectively. Which design should be selected using a risk-neutral valuation? Which design should be selected if the standard deviation for design B is 4 million? What does this tell you about risk-neutral valuations versus using utility functions?

Solution:

If we use a risk-neutral valuation, we will prefer B because its mean is higher. If the standard deviation of B were higher, we would still prefer B because mean is unchanged. This is incorrect because a higher standard deviation means there is a higher chance of doing extremely poor with B. A utility function takes us away from a risk-neutral valuation. The non-linearity in the utility function makes sure that a decision takes into account all the information about the probability distribution of the payoff.

6. How does uncertainty affect engineering design?

Solution:

Uncertainty is pervasive. Outcomes of engineering decisions cannot ever be known with full certainty. Therefore a design must to take into account the uncertainty encountered through uncontrollable factors, manufacturing variability as well as market variability. A design decision that looks good on paper may or may not be profitable or even realizable in practice. This is why proper understanding and modeling of uncertainty is important. Designers should always pursue designs that are robust to uncertainty.

7. What is a design subproblem (DSP)? Why is it important to decompose product design into DSPs?

Solution:

Design of any relatively complicated product requires division into design subproblems. A design subproblem focuses on a relatively narrow part of the design, for example design of an engine for an automobile. It is important to decompose product design into DSPs because: rarely engineers are trained in all the required disciplines, decomposed design problems are easier to tackle and decomposed problems are easier to track.

8. What are the three common ways to decompose product design into DSPs?

Solution:

Design problems can be decomposed based on: discipline, product modules and design teams.

9. Comment on how creativity affects concept generation and selection.

Solution:

Creativity is the ability to come up with novel solutions to problems. In concept generation, a good creative solution overcomes technical hurdles and provides significant advantages over the state of the art. In brainstorming sessions, creative solutions when built upon using engineering knowledge can lead to overall superior designs. Creative implementations also provide significant advantages downstream in manufacturing and marketing and can prove to be a competitive advantage.

10. Comment on the value of iterations in design process.

Solution:

Very few designs succeed at the very first attempt. Since significant savings can be made in time and money by catching errors early, a design process, or even a simple step within it, requires iterations and revisiting. Steps earlier in the design process like concept generation are therefore more critical to the process that later ones like manufacturing and assembly methods used. Researchers almost universally agree that most of the cost of a product is fixed in the design stage itself (~80%), the most important reason is that it precedes other steps. Good project managers always revisit steps in product development before moving further.

11. What is product platform thinking? How is it important for long term success of a product?

Solution:

In designing a set of related products, a manufacturer is looking to capture as much market share as possible. A product platform is the basic essentials of a product from which a set of products with slightly different attributes can be derived. Product platforms allow a manufacturer to build expertise in many different implementations of the same basic product. As a result when the customer needs evolve, the manufacturer is well placed to modify the products so that the market share remains constant or improves.

12. What is commonality in engineering design? How should it be approached? What are the pitfalls of making commonality an objective of optimization?

Solution:

Product platform design has been shown to increase the profitability of companies because the additional products, while capturing a larger market share, do not need the same amount of extra effort in design. The products share *commonality*. Commonality should be approached as an important strategy when offering products with slightly different functionality. This includes commonality in components, design methods, manufacturing as well as assembly techniques. If commonality is however made an objective of optimization, one risks compromising the important metric of profitability.

13. What is Arrow's impossibility theorem? Discuss its relevance (or irrelevance) to engineering design?

Solution:

Arrow's impossibility theorem (AIT) states that while working with multiple decision makers, no method of preference aggregation can guarantee that certain common sense axioms will be satisfied. AIT does not apply readily to engineering design. An engineering firm can represent an idealized decision maker therefore the issue of addressing multiple decision makers can, at least in theory, be avoided. Furthermore, in social science, sovereignty of all decision makers is assumed. There is no reason to assume it in engineering design because design team members have different backgrounds, seniority, as well as experience levels.

14. What are some commonly used mathematical simplifications that plague engineering design?

Solution:

Some common mathematical simplifications that plague engineering design are:

1. A function is linear in the design variables.
2. A function is monotonic.
3. There is no stochasticity in design variables.
4. There is no stochasticity introduced when attributes are calculated from design variables.

5. A random variable is normally distributed.
6. Two random variables are independent.
7. Time to failure of a component is Weibull distributed.

15. Discuss the role of optimization in engineering design. Why is it helpful? Also discuss cases where the efforts required in mathematical modeling for optimization may not be justified.

Solution:

Mathematical optimization is used to find the "best" possible solution to an engineering design problem. If a model, which is a representation of the input-output relationship (e.g. x amount of force results in y amount of deflection) in the system, is available, one can systematically attempt to find the input that finds the best possible outputs given the design constraints. Such an input is called the optimal design. Obviously design optimization brings a lot of value over an ad-hoc exploration of the design space. Optimization algorithms can solve engineering problems involving many variables and constraints, and have been successfully used in industry and academia. The down-side of optimization is the need for an accurate model (input-output) relationship. Many times the effort required in finding such a model outweighs the benefits from finding the optimal design where a simple ad-hoc approach will suffice. Moreover, in the search for models that are also mathematically tractable, many assumptions are made which can result in designs that are impractical or simply infeasible.