16 Rules of Engineering Design

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1. Consider the system to be designed as a field of requirements and characteristics. It is easy for an engineer, and all too common, to jump right into specific designs before thoroughly understanding all of the requirements that relate the subject system to its environment. To make genuine progress, it is absolutely necessary to take the time to study the problem for which an engineering solution is desired in as broad an interdisciplinary context as the problem requires. This means understanding and documenting all of the desired performance, environmental, social, and economic requirements. By the "field of characteristics" I mean all of the alternative system characteristics. One characteristic of a transit system, for example, is suspension. A vehicle could be suspended on wheels, air cushions, magnetic fields, or sled runners. The decision as to which is most suitable requires a "trade-off" analysis, which is resolved to best meet the requirements. Detailed study of the requirements must lead to a quantitative set of criteria that will guide the design.

2. Identify all trade-off issues. Suspension as a characteristic or trade-off issue in transit design is mentioned above. We found 47 trade-off issues in transit design, which certainly is not an exhaustive list. Each issue must be considered carefully in any new design. By considering such issues explicitly with the criteria firmly in mind, the task of design is clarified and organized.

3. Without prejudice, identify all reasonable alternatives within each trade-off issue. By rushing into details too quickly, practical alternatives are often overlooked; someone else finds them and develops a superior design. Perhaps more important is that the designer who has not examined alternatives carefully before committing to a design cannot defend the design rationally and then becomes emotionally "locked in" to one approach as others point out superior alternatives. All too often such a designer causes more harm than good in advancing the design of a new system.

4. Study each alternative until the choice is clear, rational and optimal. This is hard work and is where the use of engineering science and mathematics enters. If not done rationally the design may have fatal flaws. Such a process creates designs that are difficult or impossible to better, which is the objective of a good design engineer.

5. Let the system requirements dictate the technologies. I have observed cases in which the designer had been fascinated with a certain component or technique and proceeded to design his system around it. In every one of these cases the resulting system failed to meet the system requirements and was discarded.

6. Seek and listen *humbly* to comments from anyone who will listen. By explaining ideas and listening to comments, you clarify them. A difficulty many engineers have is failing to listen humbly, particularly to an outsider. Arrogance is disastrous to good design. A good designer must be humble – a rare attribute.

7. Seek advice from the best experts available in every specialty area. It should be obvious that none of us can know the details of every specialty required, yet there is often an innate desire to try to develop the design ourselves. The best design will take advantage of the best information available anywhere, from anyone. A large portion of an engineer's work involves searching for information developed by others. In the age of the Internet, this is much easier.

8. Consult with manufacturing engineers at every stage of design. In the United States, particularly, all too many design offices have left manufacturing considerations to the end of the design process. Managers who grade manufacturing engineers lower than design engineers inform the able engineer where to concentrate.

The Japanese practice of including the manufacturing engineer in every stage of the design process led to superior products that often took most of the market share.

9. Recognize that while emotion is a fundamental driving force in human behavior, emotion must not select alternatives. Emotional commitment is vital for any human being to enter fully into a task, but it must be set aside when making design decisions. A good design engineer must be free of emotional "hang-ups" that inhibit making use of all information available. The engineer must calmly sort through the pros and cons of each approach before recommending a solution and must be willing to accept someone else's idea when objective analysis shows it to be superior. Too few engineers have a deep understanding of the subconscious factors that motivate and direct thinking. Yet it is necessary for the engineer to put the ego in the background when making design decisions. The following verse from The Bhagavad Gita, written over 2500 years ago, applies today!

"Therefore unattached ever
Perform action that must be done;
For performing action without
attachment
Man attains the highest."

10. Recognize and avoid NIH (Not Invented Here). I worked for eight years in the Honeywell Aeronautical Division's Research Department in Minneapolis. Honeywell management established a design and production group in Clearwater, Florida, partly for the purpose of commercializing systems and components developed in Aero Research. It was found time and again that after designs management wanted commercialized were sent to Clearwater they were changed for the worse.

As a result, a management policy was implemented that required that whenever a project went from Minneapolis to Clearwater, the engineers that developed it went with it to supervise the detail-design process through production.

NIH is joked about, but it can destroy the profitability of a design office. The motivating drives that produce it must be understood and controlled. The human emotion that says "we can do it better than you can" is okay if it is controlled, but when it prevents an engineering office from making good use of ideas developed elsewhere, as is all too often the case, it is destructive. I witnessed a case in which this attitude resulted in the collapse of a promising industry, from which it has taken decades to recover.

11. Consider the overall economic implications of each design decision. This requires good market and economic analysis to parallel design analysis. A design is successful if it wins in a highly competitive market, and it can do so only by taking economics into account at every step. Unfortunately, cost and economic analysis are not part of most engineering curricula so too many graduate engineers are unprepared and must learn these subjects after graduation, if they ever do.

12. Minimize the number of moving parts. I have noted that some engineers become fascinated with extremely complex designs, but they too often are subject to more failures and end up with higher life-cycle cost. Examine carefully the function of each part.

13. Consider the consequences of failure in every design decision. It is easy to design something if failures are not considered. A good design requires that the best engineers perform careful failure-modes-and-effects analysis as a fundamental part of the design process. It cannot be just something tacked on at the end, as is too often the case.

14. Use commercially available components wherever practical. I have mentioned that the temptation to "design it yourself" is strong, but it is expensive and does not take into account that a design engineer cannot be a specialist in very many areas of engineering. There are of course times when a commercially available component just will not do, but such a decision should be made only after commercially available components are considered very carefully.

15. Design for function. Sounds obvious, but is too often overlooked. A Japanese engineer reduced the cost of a magnetron for a microwave oven from over $500 as developed by an American engineering firm to under $5 by asking himself what the magnetron is really supposed to do. I reduced the design of an instrument from 90 parts to 19 by asking: What was the real function of the device? The new design passed a much tougher vibration specification than the previous one and led to complete domination of its market.

16. Analyze thoroughly. It is much cheaper to correct designs through analysis than after hardware is built. Analysis is hard, exacting work. Most engineers do not have sufficient mathematical background to do such work well and thus blunder along from one inadequate design to another. This "garage-shop" approach has initiated many designs, for example the bicycle and the automobile, but modern aircraft and automotive design requires a great deal of analysis corroborated by experiment. Design of a truly cost-effective, high-performance transit system requires the best of modern engineering analysis.