An Exercise in Problem Definition in an Early Design Course

Richard Bannerot

University of Houston

Abstract

Problem identification and definition is a necessary first step in the design process, but it is often overlooked in the rush to "get started" designing. The result of a complete problem identification process is a problem statement and the resulting specifications, as described in the paper, that define the problem in some detail. Without a good problem statement and/or a comprehensive set of specifications it is difficult, if not impossible, to generate an appropriate solution or, perhaps more importantly, to evaluate the solution. We have used exercises in specification development in both our freshman "Introduction to Mechanical Engineering" course and our sophomore design course. This paper will describe these exercises and provide an example.

Preface

"The mere formulation of a problem is far more often essential than its solution…" -- Albert Einstein[1]

"The most critical step in the solution of a problem is the problem definition or formulation." [2, 3, 4]

"The starting point of most design projects is the identification by a client of a need to be met." [5]

The client's statement of need must be refined in the problem definition in which 1) objectives are clarified, 2) user requirements are established, 3) constraints are identified, and 4) functions are established. These problem definitions are sometimes difficult to communicate to others because they often contain errors, show biases, and imply solutions.[6] Engineering design involves more than simply generating solutions. In the process of engineering education, some attention should be paid to how a problem definition is formulated and how this formulation is accurately communicated to all participants: the client, the designer and the user.

Introduction

Most of the limited time available for undergraduate engineering education is used to solve problems. However, some would argue that there is too much emphasis on solving well-posed, textbook problems. In an attempt to broaden problem-solving skills, open-ended (design) problems are introduced. These problems are intended to be realistic, to increase the motivation of the students, and to better prepare them for the real world of engineering. However, in the university classroom it is difficult to achieve a workplace environment since it is difficult to consistently provide meaningful problems, sufficient supervision, adequate support, sufficient time and proper evaluation. As a result the attempts to generate opportunities for realistic problem solving are sometimes limited to a "capstone" course where students are usually expected not only to integrate all their engineering knowledge that is largely analysis based but also to know how to design despite very little design education. Many programs offer lower level design experiences that are good but many times lack the structure necessary for good engineering design.

As noted above, two very important and often overlooked aspects of the design process are the problem statement and the specifications that define the problem in some detail. Without a good set of specifications it is difficult, if not impossible, to even evaluate the solution. After all, the solution has been developed in response to a need that must, at some point, be well defined or quantified. Even more critical when interdisciplinary teams are working on problems, there must be an agreement on what the problem is. In fact, problem definition and specifications (in some form) are fundamental not only to design but also to problem solving in general.

The paper will describe how specifications are presented, subdivided, and evaluated in our introductory design course. Exercises, in which students prepare specifications for such items as: an automated pet food dispenser, a portable device to safely and temporarily lift a portion of an automobile for the purpose of roadside repairs, a lawn maintenance device, a device to address the problem of carrying heavy loads around campus, and a place to keep food cold, help students to appreciate the need for problem identification and make them distinguish between the specifications that define, among other things, function and performance and the solutions that are the artifacts of the design process.

Specifications

The term "specifications" has been used in various contexts. Specifications can spell out the measurable physical and performance attributes of a completed device, for example, weighs 100 Newtons or accelerates from zero to one hundred kilometers per hour in 7.2 seconds. Another type of specification sets key design variables such as fluid viscosity, surface hardness, and spring constants. In an introductory design course, students will normally not have the experience to set these kinds of quantitative specifications. A similar circumstance exists for anyone in the early stages of the design process when the knowledge base is limited. Therefore "specifications" for an introductory design course will usually represent an attempt to better <u>qualify</u> the initial problem statement rather than to <u>quantify</u> it. However, the objective is always to define the problem as precisely as possible, and quantifying specifications are desirable as long as they represent reasonable expectations. On the other hand, specifications must be met by the design solution. If a specific material, size, or weight is not absolutely necessary, it should not be specified since it over constrains the solution; only characteristics and functions are normally specified.

In an ideal world, the establishment of the specifications would come early in the design process, and the final device (the solution) would exactly meet those specifications. However, many times specifications are re-established as knowledge of issues increases, and it is found that specifications are too restrictive and that others could be tightened. These initially established specifications are sometimes called the “target specifications.” “These target specifications represent the hopes and aspirations of the design team, but they are established before the team knows what constraints the technology [and economics] will place on what actually can be achieved.”[7] In an actual design process, these target specifications may be redefined several times as technological and economic constraints are better defined, for example, after several concepts have been developed. However, it is only the initially defined target specifications that are the type of specifications of concern in the setting of an introductory design course.

Two issues that are stressed in the class are to distinguish: 1) between the “function or the characteristic” and the “solution” and 2) between the “aspirations” (goals) and the “constraints.” A function or characteristic is satisfied by the design “solution,” so solutions are not part of the specifications. Solutions, mistakenly included in the specifications, can greatly limit the designer’s contribution to the design. For example, one could limit the designer’s options by specifying “plastic” or could allow for alternative materials to be considered (including plastics) by specifying “a corrosion and stain resistant, durable, rigid material.” Constraints are firm boundaries to the design space, for example, be less than 5 kg; use 110 AC, 60 Hz power; and fit within a cubic volume one meter on a side. Aspirations are desired features and performance goals (for example, compactness, rapid deployment, more accurate, and cheaper than the current market leader).

The most common mistakes students make in developing target specifications are: 1) to state impractical goals, such as “lowest price” rather than “priced competitively,” 2) to impose excessive constraints, such as “unbreakable” rather than “function and remain safe under normal abuse,” and 3) to confuse solutions and specifications, such as “use a light bulb” rather than “illumination required.”

When developing (target) specifications, it is often useful to divide the specifications into four subsets:

- technical factors,
- ergonomic factors,
- economic factors, and
- heuristic/esthetic factors.

Of course, many general specifications overlap these subdivisions. However, this overlap is not a problem. In fact, it is good that one recognizes the multifaceted aspects of many specifications.

As an example of the initial thought process that might go into developing the target specifications and then grouping them by the four factors suggested above, consider the design of the handle (if, in deed, there is one) for a device that is to dispense a liquid by pouring.

- One would consider the functional requirements that the handle be sufficiently robust and securely attached to the main body of the dispenser so that it could support the expected weight in the orientations associated with pouring. The handle should be placed and shaped in such a way that the container would tip to pour as the handle is raised. These are technical factors.
- One would consider the ergonomic factors that the handle be comfortable to grasp and that the effort of pouring would be consistent with the abilities of the target population.

- The material(s) selected for the handle and the processes selected for fabricating it and attaching it to the dispenser (if appropriate) must be consistent with the overall economic requirements.
- Finally, the appearance of the handle should be consistent with the overall spirit of the dispenser and the environment in which one expects to use the dispenser.

The writing of target specifications, much like the design process itself, involves complex thought processes for which the details vary with individuals. While this activity may be difficult and confusing at first, one gets better at it with practice. The following is a list of steps that may help to organize the process and thus make it a little less intimidating: [8]

- List all the functions that the proposed device should perform.
- Identify the target audience for both using and buying the device.
- Benchmark the marketplace.
- Subdivide the functions into their basic requirements and note how these requirements fall into the four subsets of specifications: technical, ergonomic, economic, and heuristic/esthetics factors.
- Begin to formulate the basic requirements as specifications under the four subsets.
- Review the items under each subset with the overall design objective in mind, adding missing specifications.
- Write an accurate and concise statement of the intent of the design that summarizes the target specifications.
- Objectively reread and rewrite until satisfied.
- Read the specifications first as if you were the shop manager responsible for the fabrication of the device, then as the financial officer who must approve funds for the project, and finally as the consumer who must decide whether to commit the money to purchase the device. The specifications should be complete, make sense, and appear complete to each.
- Revise as needed.

An example problem is now presented:

> The need has been identified to develop an improved device that stores and preserves food by maintaining "coolness" in an enclosed space within a domestic environment. Formulate a complete and exhaustive set of specifications (technical, ergonomic, economic, and heuristic/esthetic factors) that define the problem as you understand it.

A sample solution is given in Fig. 1.

General Specifications:

Since the device will most likely be located for periods up to 25 years in the user's kitchen, extreme care should be taken to assure safety for the user, his/her family, visitors and household pets, by prevention of electric shock, fire, abrasions, lacerations, and burns. The device must provide adequate space and access for storing a week's supply of food providing refrigeration at sufficiently low temperature to prevent food spoilage and maintain freezing temperatures as desired.

Technical Factors:

The device will maintain food at the desired temperatures, provide safe access, satisfy standard dimension requirements, satisfy all laws and regulations, operate efficiently, and provide a variety of accessories.

- Conventional refrigerators provide two compartments with user selected temperature control roughly in the range –20 °C to –5 °C in one and 5 °C to 15°C in the other. This device should provide ranges at least as large unless there is a compelling reason to do otherwise.
- The refrigeration system should be optimized to reduce, to the extent possible, the amount of power required for the cooling necessary to maintain the conditions above.
- The device should be properly insulated to maintain heat gain to a reasonable minimal level, based on an appropriate economic and space available analysis.
- The temperature should be controllable in each compartment by the user.
- Each compartment should be designed in such a way that uniform temperature, such as plus or minus 2 C°, is achieved throughout the compartment.
- The actual compartment temperature should be measured and displayed for the user; it would be desirable to alert the user should significant deviation in the temperature from the set point occur in a compartment.
- The device should be powered by conventional household electricity, that is, 110v, 60 Hz alternating current and limited to peak current of 7 to 8 amps, unless a convincing case can be made to use alternative power.
- All interior spaces should be accessible through an opening(s) on one of the vertical sides of the device unless there are compelling reasons to use another mode of access.
- Access should be designed to minimize heat gain, that is, assure quick entry and retrieval and sufficient reseal capability.
- The design of each interior space should be such that it is easily accessible from the opening.
- Sufficient accessory devices, such as shelving, racks and containers, should be provided to allow the user to configure the interior space as needed. Consideration should be given to the type and shape of common refrigerated foods when designing these accessory devices.
- The outer dimensions of the device should conform to industry standards.
- Interior spaces should be as large and useable as practical given the outer dimensions, the need for insulation, and the "power conversion" compartment.
- Consideration should be given to "carefree" operations, for example, features such as "frost free" and filtered water provided by connections to the domestic water supply for an automatic ice maker and cold water. "Through the door" availability should be considered for both.
- Additional features, such as limited "through the door" access to shelves, fold down or other exterior shelving, leveling and moving ability, and noise minimization, should also be considered.

Figure 1: Specifications for a Domestic Refrigerator

Ergonomic Factors:

The device will be convenient to use by the target population and be safe for all who come in contact with it.

- While the device will be exposed to a large and diverse population of humans and animals, the user group will be defined to be able-bodied adults, standing 1.5 to 2.3 meters tall and being less than 70 years of age.
- Since the device is a consumer product that will likely be used or attempted to be used by humans of "all" ages (likely, 1 year and above) and have exposure to a variety of household pets, safety is of the utmost concern. For example, federal law requires that any doors, if used, must be capable of being opened from the inside. Materials used should be non-toxic.
- The device should pose a minimal of danger when touched: minimize the possibility of electric shock, sharp and abrasive parts, and the possibility of pinching, such as when the opening and closing doors.
- There should be easy access to all the compartment space by the user group for both placing and accessing food and for cleaning.
- The controls and displays, noted in the technical specifications above, should be accessible, readable and adjustable by the user group.
- The accessory devices, such as shelving, racks, and containers, should be deployable by the user group. Easy to understand instructions should be provided if deemed necessary.
- Whatever action associated with gaining access to the compartment(s), for example, opening and closing doors, should be consistent with the abilities of the user group and require a minimal effort consistent with the need to achieve the desired "seal-ability" of the compartment(s).
- Consideration should be given to installing and subsequent moving of the device, for example, to gain access to the "back" of the device and for cleaning or possible maintenance.
- If available, the cold filtered water and "automatic" ice should be easily attained. Filters should be accessible for replacement.
- Easy to understand instructions should be provided for installation (including any accessories), maintenance, and minor repairs.
- Reversible doors (capable of being opened from either side) would be a plus.

Economic Factors:

The device should be energy efficient and priced competitively, for both initial and operating costs, with other refrigerators with similar performance, size and features.

- Any effort to reduce price should not jeopardize safety.
- The device should be easily manufactured with current technology and in existing facilities.
- Consideration should be given to devices with a range of performance, size and features with the appropriate prices.
- Design of the device should account for its "afterlife," for example, safe disposal and recycling parts.
- Coolants should be commercially available, safe for domestic use, and environmentally friendly.
- The device should be structurally sound to survive transport.
- Standard parts should be specified whenever possible to reduce the cost of production and repair.

Figure 1: Specifications for a Domestic Refrigerator (Continued)

Heuristic/Esthetic Factors:

The device should appear to be well engineered and manufactured and sufficiently "rugged" to provide maintenance free operation for 25 years.

- The device should be available in several colors consistent with a domestic kitchen.
- Consideration should be given to take advantage of the current fad for using the refrigerator as a posting board.
- Under normal conditions, the device should blend in with its environment.
- Both the interior and the exterior should be designed for ease of cleaning. Surfaces should resist the accumulation of dirt and grime and be resistant to normal household cleaning solvents.

Figure 1: Specifications for a Domestic Refrigerator (Continued)

Comments on the Solution

The set of target specifications is much like the solution (the design) itself in that: each person will develop a unique and different solution, the solution can always be improved, and there is never a single "right answer." Therefore, the answer presented above is only one of many possible solutions.

The format selected here presents a general statement, a short statement for each factor, and a bullet-sentence structure for the detailed points under each factor. There are other formats, but each solution (each set of target specifications) must be internally consistent.

The solution has also been restricted to a "Domestic Refrigerator" rather than a food preservation device. If the scope of the problem is determined to be too large, students are given the option to split or limit their solution to a subset of the original problem. Of course, justifications are required.

Conclusions

Writing specifications is a useful exercise forcing the students to focus on an understanding of the design problem. Too often a design is attempted before the problem is completely defined. Writing specifications is also training in technical writing that students should practice. In our introduction to design course, solutions from previous semesters (for several different problems) are provided. The initial submissions are returned after careful review and, most times, with extensive corrections and suggestions for improvement. A resubmission is required.

Without experience in defining problems, it is difficult to understand how someone could effectively solve problems. Problem solving skills gained in an early introductory design class are useful to students throughout their engineering education and beyond. Organizing problems by defining them in terms of their specifications facilitates the problem solving activity and is especially helpful when dealing with complex problems in an interdisciplinary environment.

Bibliography

1. As quoted in H. Scott Fogler and Steven E. LeBlanc, *Strategies for Creative Problem Solving*, Prentice Hall PTR, Englewood Cliffs, NJ 07632, 1995, p. 29.
2. George E. Dieter, *Engineering Design*, 3rd Edition, The McGraw-Hill Companies, Inc., 2000, p. 10.
3. Paraphrased from David G. Ullman, *The Mechanical Design Process*, 2nd Edition, The McGraw-Hill Companies, Inc.1997, p. 13.
4. Paraphrased from H. Scott Fogler and Steven E. LeBlanc, *Strategies for Creative Problem Solving*, Prentice Hall PTR, Englewood Cliffs, NJ 07632, 1995, p. 29.
5. Clive L. Dym and Patrick Little, *Engineering Design: A Project-Based Introduction*, John Wiley & Sons, Inc., 2000, p. 54.
6. Paraphrased from Clive L. Dym and Patrick Little, *Engineering Design: A Project-Based Introduction*, John Wiley & Sons, Inc., 2000, p. 54-56
7. Karl T. Ulrich and Steven D. Eppinger, *Product Design and Development*, The McGraw-Hill Companies, Inc., 1995, p. 56.
8. Adapted and expanded from Karl T. Ulrich and Steven D. Eppinger, *Product Design and Development*, The McGraw-Hill Companies, Inc., 1995, p. 57-67.

.

Biography

RICHARD BANNEROT
Richard Bannerot is a Professor of Mechanical Engineering at the University of Houston. His research interests are in the thermal sciences and in engineering design education. For the past twelve years he has taught the required "Introduction to Design" course at the sophomore level.