The Engineering Design Process

A Research Paper Submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia - Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

By

Hieu Le

Fall 2020

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: ________________Hieu M. Le__________ Date: ____11/22/2020____

Hieu Le

Approved: _________________________________Date:___________________

Dr. Richard Jacques, Professor of STS, Department of Engineering and Society

Introduction:

There are numerous ways to solve a single problem, though not all of them are equally good. We had the most secure presidential election in U.S. history. However, that was not always the case. One of the biggest reasons why our voting system was vulnerable to attack the previous years is the questionable design of voting machines. There were two main types of voting machine design in the last election.

The first design is called Direct Recording Electronic voting machine or DRE. The engineers designed it to allow users to vote electronically, which also means that it is entirely paperless, and the voting records get saved inside the machine's hard drive. At first glance, this design seems like a great idea. It allows users to vote quickly, it does not waste any paper, and by the end of the day, it lets everyone know the result right away. However, what happened in 2016 includes Russian interference, voter fraud allegations, and voting machine breakdown; these brought up a massive issue about DRE voting machines. Prof. Wallach from the department of Computer Science at Rice University commented, "If something tampers with these machines electronics memory, there is no way of going back."

The second design is called Paper Backup Voting Machines. The engineers who designed these machines have both electronic and paper trail functionality. This year, according to NYT, 95% of all states implemented paper back up voting machines. Even if something tampered with these machines, we still have a paper trail for review and recount. On top of that, we have also pointed out the voter register logs to track who has voted. For that reason, many experts believe that this election is the most secure election we ever had, and it's close to impossible to have large-scale voter fraud. Even though the second design is not the most efficient, it is a better design based on its accuracy, reliability, and, more importantly, an ethically responsible design.

I think it's important to point out that the most efficient solution is not always the best solution. In this paper, I argue that to have a good and ethically responsible design, one must follow a balanced engineering design process. Engineers must not only think of themselves as problem-solvers; they need to be engineer-sociologists. Finally, users and non-users are also factors when it comes down to a design decision.

Part I: The Design Process

The engineering design process is a process that engineers employ to help develop a solution to a problem. The problem requires a solution that involves designing a product that meets specific criteria and accomplishes a particular task. There are many solutions to deal with one question; therefore, there are many ways to approach a problem. There are many variations of the engineering design process; we'll look at the process model from Dr. Khandani's paper "Engineering Design Process."

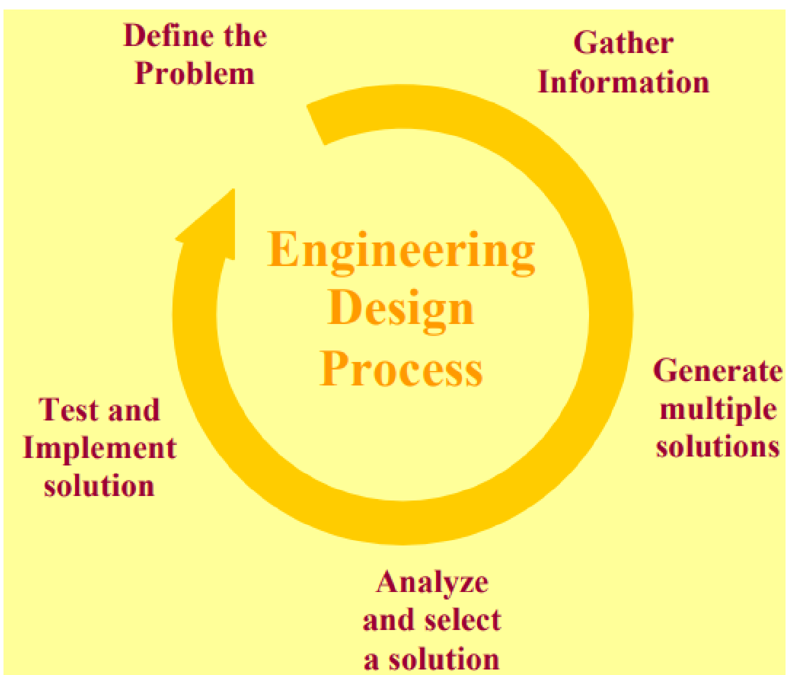

Figure 1: Continuous Iterative Process of Engineering Design

As shown above in Figure 1, Dr. Khandani highlighted the five steps used for solving design problems are defining the problem, gathering pertinent information, generating multiple solutions, Analyze and select a solution, test and implement the solution. The first step in the design process is the problem definition. This definition usually contains a listing of the product or customer requirements and especially information about product functions and features. In the next step, one can find relevant information for its design and its functional specifications. They can survey the availability of similar products. Once the design team identifies the details, inputs from test, manufacturing, and marketing teams generate multiple alternatives to achieve the design's goals. Considering cost, safety, and other selection criteria, the team will select more promising options for further analysis. The detailed design and analysis step enables a complete study of the solutions and results in identifying the final design that best fits the product requirements. Following this step, the engineers construct a prototype, and they perform functionality tests to verify and possibly modify the design. To get a deeper understanding of the engineering design process and why each step is necessary to have a successful system.

Define the problem

Defining the problem is the first step to solving the problem. Creating a clear definition of a design problem could be complicated; that's why it is essential to separate it into a series of steps or processes as you develop a complete idea. First, the engineering team must identify and establish human needs. Before one can create a problem definition statement for a design problem, they should recognize the need for a new product, system, or machine understanding of the problem. For example, many developing countries do not have access to electricity and do not have proper cooling systems. Although air-conditioning ownership had gone up from 2 million in 2006 to 5 million households in 2011, that number still represents only approximately

3 percent of Indian families. Restricted energy access prevents many from being able to purchase air conditioners. The need for a dedicated solar-powered cooling fan will significantly increase. However, one must be careful about an idea of obvious necessity; it may not be the real need.

> A common tendency is to begin generating a solution to an obvious problem without understanding the problem. This approach is precisely the wrong way to start solving a situation such as this. You would be generating solutions to a problem that has never been defined. (Khandani 2005)

The next step is to develop a problem statement and establish the criteria for a successful project. Once the team confirms what the need is, they define that need in terms of an engineering design problem statement. To reach a precise diagnosis, they collect data, run experiments, and perform computations that allow that need to be expressed as part of an engineering problem-solving process. The team must then define the criteria for success. For example, what are the requirements for a better solar-powered fan? It must be durable, easy to use, low maintenance, low cost. The electrical parts must have protections against rough usage conditions.

Gather pertinent information

One of the essential parts of the engineering design process that many engineers tend to skip is the Gather Pertinent Information. Before a team can go any further in the design process, they must assemble all the knowledge needed. In the paper "Making Mobiles African" by Prof. Odumosu, he introduces African countries' mobile uses and habits of African countries.

> The Nigerian case clearly illustrates that the local context can affect the shape and outline of national mobile telephony design, yet it is also true that there are similar factors in various African nations that can materially contribute to the creation of mobile telephony

> networks. The challenge of delivering electrical power to various base stations is a common challenge faced across most of the continent. In some areas, the problem is a problematic electrical grid, in other areas, there is no grid. These common challenges have exerted an influence on how mobile networks in Africa are designed and run. In particular, lower power, high-efficiency base stations resistant to wide voltage variability have become a mobile networking sign criterion. (Odumosu 2012)

With comprehensive research, the engineering team working on a mobile network in Nigeria can acknowledge that understanding the technical side is not enough. They should consider how the users would use the device and develop an adequate solution to handle the users'.

To gather essential information, engineers must know where reliable sources to acquire that information. Traditional publications are still a vital source of information to engineers and scientists. However, electronic information transfer and retrieval are quickly becoming an authoritative source for engineers and scientists. When you begin to search for information relating to a design problem, you must be prepared to go to many different sources. The library is still the primary source of information for an engineering student. (Khandani 2005)

Generate multiple solutions

The next big step of the process is to create numerous solutions to solve the problem. This part of the process allows engineers to be creative. A good starting point can be using the existing explications to the problem and then dissect them apart-find out what's

Wrong with those solutions and focus on improving their deficiencies. Consciously combine new ideas, tools, and methods to produce a unique solution to the problem. Bringing back the example of the voting machines, the engineers who designed these machines have electronic and paper trail support learning from other machine mistakes. Having paper backup allows election officials to look back at the votes if there were any doubts about the process's legitimacy.

> Ideas are generated when people are free to take risks and make mistakes. Brainstorming, at this stage, is often a team effort in which people from different disciplines are involved in generating multiple solutions to the problem. (Lumsdaine 1993)

Analyze and select a solution

> Once you've conceived alternative solutions to your design problem, you need to analyze those solutions and then decide which solution is best suited for implementation. Analysis is the evaluation of the proposed designs. You apply your technical knowledge to the proposed solutions and use the results to decide which solution to carry out. You will cover design analysis in more depth when you enter upper-level engineering courses. (Khandani 2005)

Analyzing and selecting a solution is one of the most time-consuming and rewarding phases of the design process. The analysis of design solutions includes Functional analysis, industrial design/Ergonomics, mechanical strength analysis, electrical, electromagnetic manufacturability testability product, safety and liability economic and market analysis, regulatory and compliance.

After taking everything from the research and past knowledge, the last step of the design process before building a prototype is the decision process. One needs to decide and document which design solution is the best. The team will refine and develop the best solution in more detail during the later stages of the design process. At this stage, to evaluate each solution objectively against the stated design criteria or requirements, you need a quantitative basis for judging and evaluating each design alternative.

Test and implement the solution

It is the last phase of the engineering process. The team must consider several implementation methods, such as prototyping and concurrent engineering, and specific activities during the performance, such as documenting the design clarification and applying for patents. The first stage of testing and implementing a new product, called prototyping, consists of building a prototype, the first fully operational production. A prototype not thoroughly tested may not work or operate as intended. The purpose of the prototype is to try the design solution under real conditions. Traditional design practices are primarily serial or sequential: Each step in the process is completed in order or sequence only after the previous steps have been completed. The implementation of the design occurs after a prototype or model is created from engineering drawings. A crucial design activity is documenting the team's work, clearly communicating the solution to the design problem so someone else can understand what you have created. Usually, this consists of a design or technical report. (Khandani 2005)

Although the technical idea seems to provide an excellent way to design a great product, engineers can broaden the view on how their designs can be taken in. The idea of Engineer-Sociologists and Non-users should also be taken into account.

Part II: M. Callon's idea of Engineer-Sociologists

In "Society in the making: the study of technology as a tool for sociological analysis," believes that engineers, when designing a solution to a problem, need to think like an Engineer-Sociologists. Engineer-Sociologist is an engineer who studies society; they learn about culture by investigations and projects.

Paper Backup Voting Machines is an excellent example of a product that was designed by Engineer-Sociologists. Engineers who worked on the project could not think of the best way to produce the most efficient outcome. Still, they had to think about the consumers, social movements, and the environment this machine operates in.

Think like an Engineer-sociologists

Callon introduces the idea of ‘engineer-sociologists’, whereby the name implies that engineers take on the role of developers that build a product and sociologists that characterize and predict the social climate in which the technology will operate. Callon supports this point by analyzing a case study of the introduction of the electric car (VEL) in France in the early 1970s. The VEL project was presented by engineers working for Electricite de France (EDF) who claimed that their new electric car could change the existing social structures in France. They described the technical specifications of the vehicle and the social climate it would operate in. Their main points were to make the car a symbol of departure in a post-industrial society, use the vehicle to progress into a new era in public transportation that improves existing conditions, and break down social categories that ‘distinguish themselves by their styles of consumption.’ EDF identified several actors that would help make the VEL a success: manufacturers, Renault (another automobile manufacturing company), the government, consumers, social movements, ministries, and the technology itself. Callon’s point in describing how the EDF engineers introduced the car was to emphasize how engineers think about the technical specifications and the sociological climate they would operate simultaneously. (Callon 1982)

Technology and social studies are interconnected, which leads to a new way to define the dynamics of technology. Using the case example of the VEL in Europe in the 1970s, developing technology can continually renew itself into something else with the actors, including elements of sociology and engineering. Scientific and technological analysis should always be combined with sociological research and a distinction can be made between the system itself and its environment.

It is vital that during the design process, the engineer should think like an engineer sociologist who can transform academic sociology into something capable of following the technology throughout its collaboration. The birth of technology has changed the social construct; it's also known as the post-industrial society. In the new era where technology development is the main factor, it's not as simple to throw away the way of life and adapt to a new one. Callon used the example of how the automobile industry is the central player in our society and could not be removed and replaced by electric vehicles overnight. They need to be slowly integrated into the population through constant social movements. One does not have to be a sociologist to study society; an Engineer-Sociologist can learn about society through investigations and projects. The engineer sociologist can transform academic sociology into something capable of following the technology throughout its collaboration.

Part III: Non-Users must be considered during the design process

The nonuser term is being introduced in "Non-users also matter: The construction of users and non-users of the Internet" by Sally Wyatt. Wyatt explains that nonusers are the one who does not use something. Analyzing who the users are and who are the nonusers are critical during the design process, not-for-profit purposes but also about ethics.

We use the example of voting machines from earlier, users are the US voters, and nonusers are nonvoters who are also affected by these machines. These people include underage US citizens, asylum seekers, the ally of the U.S.

The importance of including non-users into the design process

In the paper, Wyatt explains that she has never owned a car, even when she can drive one. Even though she is not a direct user, cars have an enormous effect on her life. Other car users have a perception that as an adult having a car is an absolute necessity. The counterargument is that's not the truth, and it is perfectly normal to not rely on the means. Should non-users be included in a conversation when designing new technology and not all non-users wishes, they could become one.

This idea of non-users who do not wish to become users could significantly shape specific devices' design. Wyatt questions the readers about the possibility of the Internet will become as dominant in the way everyone obtains their information as in the way cars dominate people's transport choices. She also notes that it is increasingly difficult for non-users to get the information they need without having access to the internet the way non-car-users have difficulty getting to their destinations. Let us look at an example of phone uses in Hong Kong.

> Other new technologies indicate patterns of use and nonuse. Leung and Wei (1999) examine the use and non-use of mobile phones in Hong Kong. Mobile phones have a much longer history than the Internet as a consumer technology. Leung and Wei identify the important factors in determining the take-up of mobile telephony, although they do not distinguish between people who have never used a mobile phone and those who have stopped using them. Age, income, gender, and education all work in the expected ways. However, age dominates is one is older (unspecified), having more money and more education does not make much difference. Income levels are declining insignificance, thus providing some support for the effectiveness of "trickle-down. The intensity of use of mass media is not significant, but belonging to social groups that us mobile phones is. Equally unsurprising is the finding that-users perceive the technology to be unnecessary

> because they have an alternative or because they find mobile phones either complex to choose and use or intrusive. Leung and Wei's results confirm a growing gap between the communication-rich and the communication poor, with users of mobile phones more likely to possess a range of alternative and complementary forms of telecommunication (pagers, answering machines, etc.), whereas non-users had only one reasonable alternative. Leung and Wei accept the premise that having multiple communication devices is intrinsically good, whereas having only one adequate communication device is a sign of deprivation. Leung and Wei's results are not very surprising: people do not use mobile phones if they have alternatives, find them intrusive, and/or think them expensive. By extension, maybe some people decline to use the Internet because they have alternative sources of information and forms of communication that are appropriate to their needs, or because they think it is cumbersome and expensive. (Wyatt 2003)

This shows how people will choose alternative sources of information and communication methods if they are less expensive and easier to use than the Internet. Wyatt mentions people who give up on using the internet due to various reasons as “dropouts.”

Analyzing the users is essential. It is also vital to include non-users in the conversation because they also shape the way our society progresses. The non-users being considered “behind” and “need to be taught” should change. Voluntary rejection of technology should always be considered in the design process.

Conclusion

In this paper, I highlighted the importance of the design process to have a good and responsible design. Engineers do not need to follow every step of the process exactly; the engineering design process can be flexible. Using M. Callon’s form, I have highlighted the idea of Engineer-sociologists and why it’s essential. An engineer-sociologist is accountable for his/her creation and how it affects society. The design process must include non-users because they have their effect and be affected by design. It is ethical to learn and be aware of what our system could affect someone, even those who have never used it. I believe that all engineers should think about and be mindful of the impact on their design. We, as engineers, should consider these factors to design a fair and responsible product.

References

Seyyed Khandani. (August 2005). ENGINEERING DESIGN PROCESS. Saylor.org. (August2005). https://dphu.org/uploads/attachements/books/books_2547_0.pdf

K. Thelwell, “Cooling in Developing Countries,” *The Borgen Project*, 18-Dec-2018.[Online]. https://borgenproject.org/cooling-in-developing-countries/.[Accessed 16-Sep-2019].

Ertas, A., Jones, J. C., The Engineering Design Process. John Wiley and Sons. New York. 1996.

Lumsdaine, E., Lumsdaine, M., Shelnutt, J. W. Creative Problem Solving and Engineering Design, McGraw-Hill, Inc. New York. 1999.

Sanders, M. S., McCormick, E. J., Human Factors in Engineering and Design, McGraw-Hill, Inc. New York. 1993.

Dym, C. L., Little, P., Engineering Design: A Project-Based Introduction. John Wiley. New York, 1999.

Hyman, B., Fundamental of Engineering Design. Prentice-Hall. New Jersey. 1998.

Michel Callon. 1987. Society In The Making The Study of Technology As A Tool For Sociological Analysis. MIT Press, Cambridge, Mass. 1987

Sally Wyatt. (2003). Non-Users Also Matter: The Construction of Users and Non-Users of the Internet. Now Users Matter: The Co-construction of Users and Technology, 67 - 79. Oudshoorn, N.; Pinch, T. ASCoR (FMG). 2003