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Creating Total Value Engineering Through Combining Design for Manufacturing and Design for Six Sigma Constructs

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ABSTRACT

Creating Total Value Engineering Through
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The modern manufacturing world has been driven to compete in a more international and interconnected system. This has led to increased focus upon frameworks and architectures to guarantee quality, high market acceptance, and reduce cost. Modern manufacturing design processes evolved largely from Henry Ford at Ford Motor Company, and Alfred Sloan at General Motors. Their structures embody two different focuses on quality and value engineering which have influenced many recent design frameworks. In the 1970s a heavy emphasis was placed upon Design for Manufacturing, which uses group technology, commonality of processes, and continual focus to reduce part count. Some companies have desired a design process that better accounts for new market needs and Voice of the Customer changes, allowing them to break out of the old processes by using a new framework called Design for Six Sigma.

Contextual and survey analysis contrasting DFSS and DFM showed these systems have different definitions of what creates value; which causes a different focus on how to improve value. As the market frequently errs at knowing when to apply DFM or DFSS, using a simple case study of a product with high part and assembly cost, teams were challenged to create a better flashlight using both DFM for part reduction, and DFSS for function improvement. The aim was to increase value. Value has been defined by the formula: value = (performance + capability) / cost or as value = function/cost. Results from the case study combining DFM and DFSS constructs demonstrate a total value engineering construct. It was also shown that DFM indicated effectiveness for a slow-changing market with cost reduction focus, and DFSS demonstrated effectiveness for analyzing continually changing market needs. Disruptive innovations can replace a formerly lull market, for which DFM can be completely unprepared; while DFSS is not effective in slow product-change markets. Incorporating the best of DFSS and DFM creates a Total Value Engineering framework.

Keywords: David Christensen, DFSS, six sigma, design for six sigma, design for manufacturing, value engineering, total value engineering

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1 INTRODUCTION

1.1 Background

In the systems and manufacturing engineering fields there has been great emphasis on improving overall quality while reducing cost and cycle time of production. This has led to numerous solutions improving quality or reducing costs, but each defines quality or value differently. When mass manufacturing became common in the early 1900s, even the two largest organizations, Ford run by Henry Ford and General Motors run by Alfred Sloan, had different definitions of value and how to achieve quality. Ford focused heavily on the reduction of product cycle time and reduction of cost per product and the removal of waste in production processing. (Ford, 1922) Sloan focused General Motors heavily on an increased-value process by understanding and creating designs that would drive the future markets desire. (Sloan, 1964) Sloan devised policies for design and improvement of the product, while Ford worked meticulously to improve production methods and reduce product cost.

In today's modern society, we consistently see the conflict between design focus and process reduction or part-cost reduction focus. The most noted framework of design focus for building in quality is Design for Six Sigma, while the modern Ford-type thinking is a part and process reduction theory titled Design for Manufacturing. Buy working to adopt both of these frameworks the goal is to find a new more effective approach that works in redesign, new design, and old design improvement, across the variations of real market circumstances.

Moore's law has been used for nearly 50 years to explain the growth rate and evolution of the microprocessor or data-storage industry, and it has been relatively consistent. (Mack, 2012) The rate of car change in Sloan's day was tremendous, much to the same rate of micro-processors over the last 50 years. Sloan's methodology of designing a new model or car for each price range for each year has been a successful model for micro-processor companies like Intel. (Schaller, 1997) But the industries with such consistent rate of change are limited. Most industries experience variable or unsteady changes in the rate of growth; being stuck with using either the DFSS or DFM frameworks singly will hinder the ability to recognize when market shifts are occurring and the other framework would have greater success. A combined construct achieves these aims.

1.2 Objective

The objective of this research was to use the Design for Manufacturing framework with the Design for Six Sigma tools in a simple, testable process, in order to come to an understanding of how the two may be combined to create a more complete "value engineering" model. Value engineering has been defined under many names, like productivity, which has often been debated as whether it means a focus on efficiency or effectiveness. DFM often describes its value focus as using group technology to enhance a present product, while focusing on reducing part and process time, while decreasing part or assembly cost. (Anderson, 2010) DFM does not focus on large function or product change.

Design for Six Sigma comes from the premise that a present product is no longer meeting the marketplace needs, and it focuses heavily on how to create value in the eyes of the customer and make a new product to fill that need. (Creveling, 2003)

Both of these processes fit the definitions or goals of value engineering. The key objective is to take a fuller view of value engineering, and use the Design for Six Sigma principles with the Design for Manufacturing framework.

1.3 Problem Statement

Because Design for Six Sigma is heavily focused on new products and Design for Manufacturing is focused on present or existing products, the two seem to operate as different functions. Review of Ford and Sloan manufacturing design frameworks show the concern of whether to design a new product or maintain an old product while improving the process and reducing part count has existed for over a century now. Ford was known for having the longest standing and most sold single high-end product in the last hundred years. In his autobiographies he states that he constantly focused on how to reduce part count and process time. This led to significant changes in manufacturing process but rarely actual design changes. (Ford, 1922) He sold over 15 million Model Ts, over a 20 year period with many process improvements, and very few changes to the product. Thus, overall the product remained the same Model T. This model if it were defined today would be most commonly associated with the Design for Manufacturing framework. He was committed to continually improving process while maintaining the character and integrity of the original product. (Ford, 1922)

With Sloan and General Motors we see more association with Design for Six Sigma. He focused on creating new designs and often completely different processes and product groups, as the potential market changed. (Sloan, 1964) Although his methods did not yet use Six Sigma as the quality marker, the entire oversight and design process correlates heavily to DFSS.

Because these companies competed nearly 100 years ago, and in the end the generative process of Sloan's General Motors defeated the old Model T, it would be of value to explain this is not the first time in the history of our country that market changes drove function improvement. Ford dominated his industry for a time, even Sloan referring to Ford said, “No one can compete at his pricing.” (Sloan, 1964) Designs for Manufacturing improvements allow a company to maintain a lead for a time, but as new functions, features and technology are introduced, the old technology is replaced. (Christensen, 2013)

By recognizing large modifications and the advances in technology, soon a new market type or product type can enter the market place and defeat the old segment. (Christensen, 2013) General Motors was able to adapt from the roadster look to a car that was closed and able to be used year round. GM lowered the frame, added an automatic transmission, added front-wheel suspension, increased engine efficiency, and provided many other “kaikaku” type innovations that the Design for Manufacturing mind-frame at Ford could not conceive. (Sloan, 1964) “Kaikaku” is a Japanese term used often to denote large scale innovations.

Many manufacturing models for improvement and product design are available. Because of this many companies try ineffective mixtures without understanding which constructs their business needs to implement. Does one implement the Toyota Production System, Theory of Constraints, Six Sigma, ISO standards, Design for Six Sigma, or Design for Manufacturing? Because they do not understand the goals of each of these individual programs, many companies use these programs for the wrong purposes. Some of these approaches are useful to reduce inventory, or increase production, or maintain profitability, but the Design for Six Sigma principles and the Design for Manufacturing frameworks are specifically focused on how to create better products that meet the market needs, even if they go about it differently.

One of the largest concerns with manufacturing is determining the rate at which an industry will change. Companies in industries of similar growth rates can easily make new products each year in order to prepare for the market changes. But there are significantly more products in industries where the customer does not desire a new product improvement, or the market variation is unstable and creating a new product each year will not effectively match the cycles of the market. (Christensen, 2013)

Companies that find themselves in slow market changing industries, often implement standard products that rarely need major changes that a Design for Six Sigma process would be effective for. But the risk for these companies that see their industry as “stable” or “unchanging” is accepting manufacturing systems and tools like ISO standards that may limit their preparedness for change. The companies that maintain the lead in these relatively slow markets or industries, end up implementing programs like DFM, which allows them to continually focus on maintaining the product with a focus on improving assembly time, assembly or manufacturing process, and part reduction. (Anderson, 2010)

The work presented in this thesis evaluates and develops a model of value engineering using both constructs, DFSS and DFM. This will lead to recognition of whether a product redesign or a new product direction is needed in any company that uses the framework.

1.4 Justification

There is no perfect scenario to use a part and cost reduction process like DFM, and there is no perfect scenario to only focus on function improvement models such as DFSS. In many industries, it will be stable for a 5-year period, which will then be disrupted by major advances of a new technology, followed by another lull. The companies that find themselves in these industries are left behind when the new market changes occur. Disruptive technologies that often replace a present technology can be obvious after created, like the automatic transmission at Sloan’s GM or it can be less obvious like a new transistor approach. The goal is finding real solutions that will benefit the companies that don't know when to focus on DFM or when to focus on DFSS. Because of the large market confusion and the numerous stories of market leaders who held the top spot for 10 years or more only to be replaced when a new product took their market share, there is a strong need to create an effective framework that can prepare companies for both market circumstances. (Christensen, 2013) The one thing most great business leaders say kept them on top was being paranoid that someone else can replace them. (Liker, 2004) The goal of this new framework will be to remove the paranoia, and give a model to make true decisions with data through a "True" value engineering construct.

1.5 Hypotheses

By performing a case study with a simple product, a flashlight, and evaluating work performed by teams of students in the Brigham Young University Design for Manufacturing course the following hypotheses will be tested.

1) Using a combined DFM and DFSS construct creates a more complete design approach that has potential to achieve higher value scores than either construct could alone.
2) Over-reliance on either the DFM or DFSS results can blind a company to not properly combine the two constructs.
3) Using DFSS too aggressively can cause the company to forget key dis-satisfiers that must be present in the design.

1.6 Delimitations

Design for Six Sigma is a broad construct. It is a set of tools that can be applied in cohesion in order to understand market changes. Because the user of the tools can choose which tools to integrate and how to define their market conditions and testing, there is a great deal of variability that can occur. In order to reduce the variability the BYU course was structured using the same DFSS toolsets and DFM framework. Thereby the results that come forth from multiple similar group projects are effective to give insights into the deployment of a DFSS and DFM combined construct.

By using a single product in the case study versus analyzing hundreds of design processes using varying DFM and DFSS frameworks, the information produced will provide a model that may be applied across multiple industry circumstances. The flashlight industry is an industry with a stable market not controlled by few companies. It is also prone to spurts of evolution in lumen design, battery power, and other function changes. For these reasons it is a bridge industry to assess both key frameworks, by its relatively slow-change nature, fitting perfectly for a DFM culture, but also potential for macro-innovations that allow for a DFSS culture. Although it may be one of the more effective industries to evaluate, since it is only one industry there are still understood limitations. Other studies using this same framework on extremely fast, or extremely slow-growth industries would give an even fuller picture when coupled with this case study.

Delimitations could occur due to result bias in the self-performed surveys, thus creating the potential for a false "random" selection process. The groups often provided open-ended questioning on Facebook and other tools rather than using contextual analysis. Because of the tendency for some teams to have been stuck on the novel ideas they came up with, and because their market was a professor, rather than actual market needs, some designed for whether the professor would like the design or not, rather than fully focusing on whether making such novel changes could affect the actual markets acceptance. Although the groups focus led to bias to over-perform DFSS changes, the results are useful because we see the risk of excessive DFSS in a more-moderate growth market.

Even with these potential biases and potential errors in Voice of the Customer and QFD processes, we gain a clear insight into both design processes for part reduction and function improvement. And with the understanding of these potential delimitations, guide our contextual and market analysis in order to draw conclusions and create a Value Engineering model that will be useful.

2 LITERATURE REVIEW

2.1 Need for Design Improvements

The market has demonstrated that products that are designed with competitive foresight and market understanding earlier in their design processes are likelier to have a higher success rate and have lower quality issues (Creveling, 2003). The wise use of design tools in new product development has significant impact on competitive advantage. (Booker, 2012) When a company creates a product without correct understanding of market or production needs, there will be an increase in design changes that are required, and an increase in production process changes. (Antony, 2002)

If a company falls into one of the major production traps of either not making changes soon enough, making the wrong changes, or implementing poor design processes they are significantly more likely to experience failure. (Connor, 2011) For this reason after the early innovators of Ford and Sloan, the market began to notice a need for best practices in production and design. In the 1960s there grew an even heavier focus on applying design principles. The Design for Manufacturing methods led to other adaptations including designing for assembly, designing for shipping and almost every other activity that can affect cost, time, or quality (Mak, 1996) Now some organizations are concerned that mixtures of present frameworks may work better than any present system alone (Nnaji, 2011)

2.2 DFM

Design for Manufacturing was born out of the excess waste that was accounted for in many production processes in the 60s. Companies turned to a solution to decrease costs of manufacturing and assembly because of the risks that come from making late engineering change or poor process choices. The goal is to have a system that provides best practices, as DFM does, so companies can limit the risk of process and material choice. (Swift, 2013) DFMs primary focus is to aim for part and process reduction while maintaining function requirements. (Anderson, 2010) Because modern companies need effective systems to protect against decreasing quality in design while maintaining the global supply chain, DFM has grown to include many different subsets: design for multiple-step assembly, design for shipping between supply chain, and more (Lefteri, 2012). The growth of the DFM framework has even become listed as DFX, the X filling the variable for the many different aspects that must be accounted for in the development, production, utilization and disposal phases. (Mak, 1996) The point is that many companies have expanded this framework to be so broad that they are accounting for many things beyond the original structure intent. The frameworks have become large and if applied for all the potential DFX subsets, it can be daunting. With this understanding, companies that apply DFA metrics save 45% on assembly cost (Swift, 2003). And multiple studies have shown reduction in cycle time.

For this reason, DFM typically takes a present product and finds ways to meet its present functions, often using similar process and group technology, but aims to reduce part count. (Anderson, 2010) Over the decades, it has become more consistently focused on cataloging process and assembly technology and material costs, in order to maximize part and process quality and reduce cost defects (Wakil, 2002). It is largely considered a cost improvement construct rather than a function improvement construct as noted below regarding DFSS. It uses catalogued cost and process frameworks in order to create critical determinants about axis of rotation, joints, and process options to best achieve the desired result. The goal is to choose the best processes and design for both assembly and manufacturing (Boothroyd, 2010). In Figure 1 we see with lower number of parts, the cost of higher defect ratios is minimized, but with the increase in parts the likelihood of a single parts failure, is compounded, whereas, barely over 50 percent of a product with 40 parts will be defect free, if each individual part has a 30% chance of having defects. This shows the need for part reduction as a defense against quality issues and cost increases. (Boothroyd, 2010)

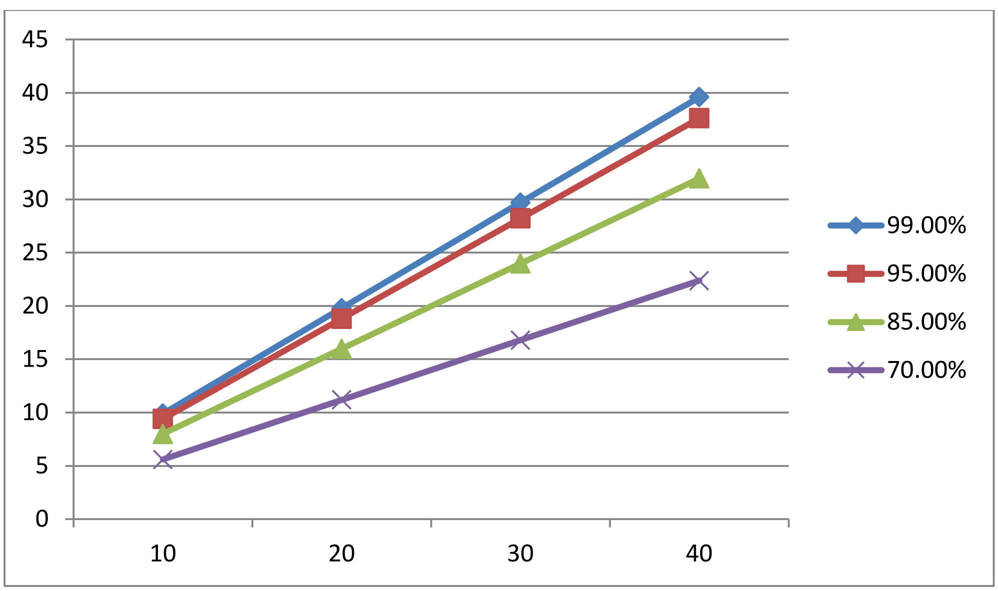

Figure 1: Example of Increasing Risk of Defects by Increasing the Number of Parts

2.3 DFSS

Design for Six Sigma is a broad construct that grew out of the need for a more effective tool set with increased speed and reduced design cycle time while meeting the high standards of quality set by Six Sigma. (Gardner, 2013) As noted above, the DFM framework grew out of concerns of how to minimize design risk and control product design to present valid processes, while DFSS grew out of a different need. The Six Sigma process was created to remove defects from present products, but had a glaring lack when it came to new designs. The goal of DFSS is to build in a reduction of defects and design in quality according to a voice of the customer process. (Chowdhury, 2002)

Because the market has moved towards shorter life-cycles and the fear is what companies are coming out within 6 months that will beat the present product many companies are seeking a more robust, value creation design process over a cost reduction process. (Gu, 2004) By implementing DFSS at Motorola they were able to drop their failure costs by nearly 84 percent. (Booker 2003) The market acceptance of products that go through DFSS analysis is 3-4 times more likely to have market acceptance and live longer. (Yang, 2003)

Since DFSS is focused on value improvement, quality increase, and meeting the customer needs, it allows for an assortment of DFSS and six Sigma constructs to be tied into one package. (Dale, 2007) Thus one company will discuss their use of DFSS in a different fashion than another company. Because of this open construct, the tools that can be applied in cohesion in order to understand market changes and to prepare the design process based off all manner of industries different customer function and feature needs. DFSS can be applied effectively across broad design and system needs. (Yang, 2008) The DFSS architecture balances the markets desire for new or change, with the need for increased standards. (Creveling, 2002)

In defining tolerances of a product, it is often hard for first time design engineers to understand the process of taking customer subjective qualitative opinions, which is sometimes the only available information, to create effective tolerance ranges. (Creveling 2002) When the product is clearly a weight tolerance allowing for plus or minus .1 grams to fit within the desired sigma range it is easy for the students to design products to meet those requirements, and to validate whether the product has met those requirements as can be seen in Figure 2 below. Taking qualitative data, which is a large portion of designing a better product, requires a whole different skill-set to assess the customer needs and design something that meets that want. (Creveling, 2002)

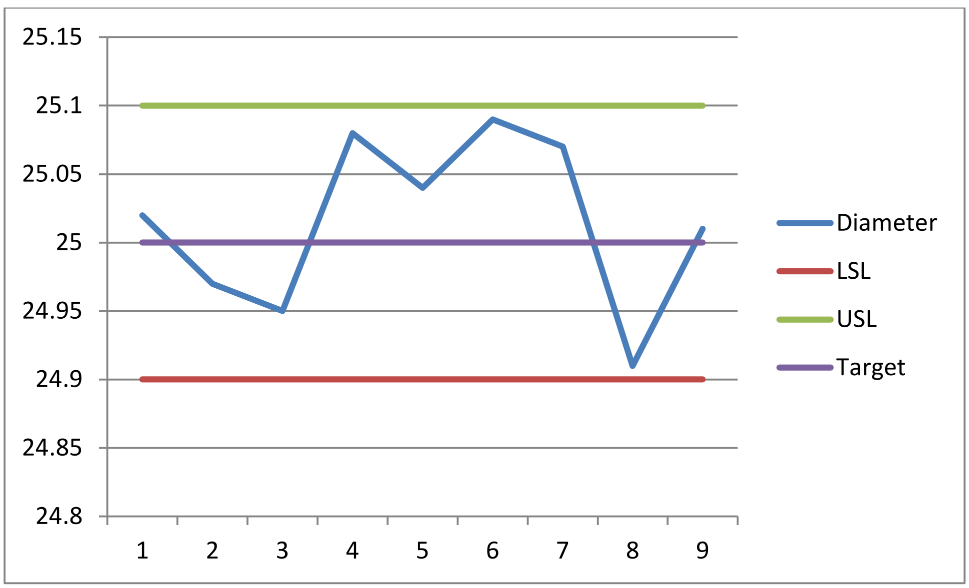

Figure 2: Exhibiting the Ease of Defining Tolerances in Quantifiable Data

2.4 DFM Contrasted with DFSS

DFM was intended as a solution for old product improvement. But many of the constructs are built around taking a present product, its present function, and finding ways to maintain function, while reducing cost. (Boothroyd, 2010) Because it is largely considered a cost improvement construct rather than a function improvement construct, DFM is often not discussed with function and feature improvement constructs like DFSS, QFD and House of

Quality. But some literature has discussed the potential power of combining the features of DFM and DFX with DFSS and other design principles to build an engineering systems approach in design. (Pahl, 2007) This is a critical point gained from the research literature and from the class experience that potentially a construct to systemize all these features together would be most effective for the market place. (Pahl, 2007) The nature to think of design improvements often requires a different kind of view and thinking than is found in DFM thinking.

DFM uses catalogued cost and process frameworks in order to create critical determinants about axis of rotation, joints, and process options to minimize assembly and production time. (Boothroyd, 2010) The goal is to choose the best processes and design for both assembly and manufacturing, to reduce worker handling time, material cost and defects. As noted above, they will often use existing group technology and process technology, because they know these methods, are assured of their quality and time for manufacture and assembly, but will analyze with the focus to find potential improvements within the processes or parts. (Boothroyd, 2010)

A large consideration in the reduction of part count is the increased costs associated with additional parts, additional assembly, and increased risk of quality issues with the increased number of components and processes. Boothroyd focuses heavily on choosing wiser product design that will make manufacture and assembly easier, but the overall understanding of market changes is missing. (Boothroyd, 2010) This is why DFM can be assessed largely as an operation view and a cost reduction focus rather than a market or function change view as DFSS is. The best way to compare these two different constructs is like saying that accountants and sales people are alike, because they both focus on money. In further examination we know the accountant sees money completely differently than the sales person; just as the DFM thinker sees the market differently than the DFSS visionary.

2.5 DFM and DFSS Concurrent Design Research

Seeing the glaring weaknesses in both constructs by themselves, multiple companies and research groups have attempted to create a further construct integrating the two approaches, some using a micro-integration using either as the primary framework and then including micro adaptations using the other framework. (Tsai, 2008)

Oxy-Fox inhaler used the two programs in a concurrent design effort to create a more robust process that was able to adapt to the market changes, while allowing for the advantages of present group technology while integrating advanced function enhancement. The author felt that specifically the Six Sigma toolset allows the production of the highest quality and lowest cost. (Brown, 2014)

Lockheed Martin Corporation created a DFM/DFSS combination framework for training its engineers that focuses heavily on the Voice of the Customer process that had heavy emphasis on how to recognize customer desired inputs alongside features and products to include. The main discussion is how to apply QFD aspects in the House of Quality process of DFSS. (Lockheed, 2001) Little data has since been shared by Lockheed whether they had continued with this framework, or if they had expanded it, or whether it was applied specifically in that form to a production or design process.

Samsung has applied the DFSS model as its primary design enhancement method. In doing so they use an additional discussion of DFM as a side principle into DFSS, it is not treated as a main framework, but one of the many aspects they sort through in their new function improvement process. (Shahin, 2008)

2.6 Ford

Many modern historians focus on Ford's use of assembly line technology as his great achievement. Any quality engineer knows that increasing process capacity without understanding how to manage inventory and wastes ends up with only increased inventory, higher costs and lower overall defects. The success of Ford was his continual focus to reduce waste, decrease material costs and continually reduce process time. Historians also attribute to him; his comment that you can get a Model T as long as it is black as proof that he was not interested in change. The truth is Ford made changes continually; he just chose to focus on process and assembly changes, rather than large scale product changes. His methods closely resemble the cost reduction methods found in DFM, which is why a general understanding of his approaches is needed. He used a whole company approach towards time and product reduction, but led the changes by using management and engineering oversight. (Ford, 1922)

Ford's processes changed so often, that a biographer who visited his Dearborn plants noted that nothing seemed to operate the way it did before. He found that decreasing total process time and improving the properties of materials while reducing total material needed would lead to the same function, with lower cost. (Ford, 1922)

Ford grew up as a tinkerer. His history with Edison's company before starting his own taught him how to "use the Edison method" to find solutions, and the experiences with money men who wanted to charge the highest amount for a product, and keep the production small, drove him to want to create a completely different company. After buying out the investors who opposed his vision of producing a car for the masses, he really began to change things. His first goal was to get rid of all waste as it hindered him from using the best methods and fastest processes. In fact when Taichi Ohno, credited as the father of the "Lean movement," was asked where he came up with the concept on waste, he responded from studying Mr. Ford. (Liker, 2004) Ford considered the public the largest beneficiary of advancement. He believed that if he could find his way to produce a part for cheaper it was his obligation to do so. Ford's quality and production engineers spent their time continually searching for faster and more efficient methods, and took upon any technology improvement in production of ore, metal, glass, and shaping of parts that they could. (Ford, 1988) This resembles the DFM mentality which has led to a catalogue of material costs, manufacturing methods, and ease of assembly handbooks. (Boothroyd, 2010) Ford had a book that showed process times and explained improvements in assembly processes in each of his divisions. (Ford, 1922)

Ford was what I would call an innovator within the product. Ford believed that his product should drop in price from year to year because each year improvements in the process should make it so. The concept of reducing part count, assembly time, and overall cycle time were Ford's largest drives. He knew that if a part sat in inventory it was costing him money. He focused on reducing float time between raw material, processing, and shipping. (Ford, 1922) Many of his ideals were translated into the modern Design for Manufacturing thinking, as will be more clearly seen later.

Ford became obsessed with end to end manufacturing because he had a strong desire to limit waste in the process. He started out only focused on how to make a good car. But because he was so focused on decreasing cost and reducing process time, that whenever he found a company that was wasting its resources, or needlessly taking a profit, he decided to move in and replace that supplier. In his own self-promoting words, it was never for gain, but only because he wanted to deliver better quality at a cheaper price to his customer. Near the end of the 1920's Ford had broadened his process so completely that his company had taken on almost every single aspect of production from the mining of ore to the shipping, even buying out railroads. In fact he states that from ore removal, delivery and all processing of the material, to a completed car was 81 hours. (Ford, 1988)

Business historians say that Ford was the largest centralized business in the world, as they discuss the size of his plants, the control over the workers life, and the production systems he used from extracting ore or coal, to the delivery and processing, on up to the manufacturing of his car. But Ford clearly states in his own words, that his company is the most decentralized company in the world. (Ford, 1988) He brags of the nature to take on any new industry, and put the right management in place to oversee it, so that he doesn't have to. I recently read a book called Fordlandia, which explains a process that Ford's company went through in order to produce their own rubber from their own trees that they grew in Brazil. It is a remarkable read of the politics and struggles of dealing with new cultures, but the author clearly states, Ford had little interaction with the production, and never once did he travel to Brazil to oversee the work. His method of production was hiring good men and getting them to always focus on improving their product. (Grandin, 2009)

Ford taught his people to value their resources, to value their customer, and to never stop improving their processes. He has multiple chapters in his books dedicated to waste reduction, and to getting every valuable part out of every resource supplied. He talks endlessly about his engineers' improvements in glass, which people at the time thought wasn't possible, his improvement in ore refinery, and his use of power in his lift and assembly line processes. He never speaks of buying out suppliers or using assembly lines as the aim, it was always to improve the process and reduce waste. He touts his ability to create standards to 1/10,000th of an inch in some processes and the effect it has on quality and speed of production that comes from consistency. (Ford, 1988) Many historians miss the underlying focus and determination that drove process improvement: the desire to make the same part faster, better cheaper, with less material and with higher standards. This is why Ford should be considered the founder of Design for Manufacturing, because the continual effort to make slight improvements on an already successful product in reducing part count, product time, and assembly time. (Ford, 1922)

2.7 Sloan

In a business graduate-level organizational behavior class, this professor stated in a condescending way "we can thank Mr. Sloan for creating our hierarchical, centralized and ineffective, slow-to-change modern organization." At the time, I had not studied Sloan, nor did I know anything about General Motors history and took the professors words as truth. Sloan's 450 page autobiography shows that professor couldn't have been more wrong. Sloan like Ford was an engineer before a businessman. He had sold bearings that were crucial to many of the automobile companies. After his bearing company had done business with Ford and General Motors founder William Durant for years, Durant sought to buy out Sloan's little company. It was a huge blessing to General Motors. Durant was a visionary, but without process improvement skills, or organizational and financial policy, his different brands and product lines were suffering under older technology and significantly higher costs than Ford. Durant's vision to try to sell different cars with different features was novel for the industry, but he wasn't succeeding due to advances in production methods not being shared effectively between one division or brand and another. (Sloan, 1964)

Just before 1920, Mr. Durant, a poor organizer of his business, was forced out of the company due to extreme personal debts and company fiscal irresponsibility. The company, even with many product lines and brands, was still being heavily outsold by Ford's lower priced, larger distribution single model operation. Historians incorrectly assume that this meant that people preferred mass-market single products over individualized products, but it is comparing oranges to sand. People got what they could afford and they knew worked, GM was not offering the quality Ford was, but Sloan would be the man to change the destiny of the company. He recognized there was no process for design improvement; he found that one successful process would be used at Chevrolet while Buick had no knowledge of it. Coordination of methods was lacking, financial controls missing, and an opposition and ego between divisions hindered process improvement and cost improvements being shared between brands. He wrote heavily of quality losses because the divisions were not driven to adapt newest methods and improve to newer market demanded designs. (Sloan, 1964)

Sloan implemented a radical approach that allowed integration of all the divisions and their process improvements. By increasing communication and information flow he structured committees that would build new design and product improvements on a yearly basis, separate from the divisions so they could continue focusing on cost improvements in the already present processes (Sloan, 1964)

Sloan recognized the power of the markets perception and built his organization specifically around large product changes, this meant new designs, and significant advances in the technology. He instituted the first hard top, mass produced car, lowered the chassis and body designs, and implemented rounded curves, widening of the car and lengthening of the body, and fathered the automatic transmission. His vision and perception of what the market would be willing to buy, is very consistent with the effective constructs used today in the DFSS voice of the customer processes. (Sloan, 1964)

2.8 Kano Model

In DFSS the Kano model is used in the House of Quality to assess properly that the engineers do not miss critical requirements for a specific function. The Kano model defines requirements on 3 tiers: basic and often unspoken dis-satisfiers because they are expected, variable and often spoken satisfiers, and exciting or delighters as the highest tier. Many DFSS experiments have shown that if a product is produced with the variables desired but a dis-satisfier is forgotten, the person will very quickly pass on the product. (Creveling, 2003)

2.9 Value Score

Value engineering was a large focus of the early design movements that led to DFM thinking. GE during the World War 2 era desired to make value or cost- reduction thinking the primary objective of their manufacturing processes (Miles, 1972).

During the war, shortages and rations crippled many production industries and processes. GE recognized the need to improve processes in a way to limit waste of material, and protect against cost increases and material shortage. Because they were less concerned about design improvements, they titled value engineering, the phrase, as a process of waste or cost reduction. It meant reducing the parts or processes used while maintaining the present function (not increasing or reducing function). They spent time researching materials or techniques that would get the same result, but for cheaper, without changing the way the product would operate. The worry was that changes in product or process would lead to a decrease in quality, and for this reason a heavy emphasis on meeting present function but with a cheaper product or process was formed. (Miles, 1972) This correlates heavily to the processes in DFM, and even earlier to the thinking of Ford. It is largely focused on reduction of the denominator in the value formula that is often used by many value analysts, value = function/cost. (Fallon, 1980)

This ratio to represent value as something that can be enhanced by either improving function, reducing cost, or doing both, has been slowly redefined ever since the 1940's when GE introduced a value engineering construct. In more recent eras, new product enhancement has created frameworks with a focus on feature improvements. (Fallon, 1980)

3 RESEARCH METHODOLOGY

3.1 Introduction

Using research based off team prototypes and post-prototype analysis the method was to discover how to create a more complete value framework using DFM and DFSS. The research analysis process was performed first by accessing the DFM course frameworks to evaluate the group processes and accuracy of cost and process reduction. The DFSS interview process used by teams was analyzed. Then contextual analysis and value scores were generated with a construct comparison to the original flashlight in order to guide a fuller value engineering perspective.

3.2 Group Projects

The group project evaluation was two parts 1) organize and understand the DFM and DFSS constructs as used by the groups, and 2) locate differences between each group in how they applied Voice of the Customer and House of quality subsets. By understanding the differences between the groups and how heavily they focused on novelty, the results exhibit which groups were more focused on DFM or DFSS frameworks when they created their new design and performed customer analysis. This process helped assess further contextual analysis and foster a further comparison value score against the original flashlight.

3.3 Perform Contextual Analysis

In order to understand the DFSS constructs, the Kano model was used to assess if the engineers missed critical functionality the customers would require. Because the Kano model defines requirements on 3 tiers, the method was to locate dis-satisfiers which were most likely missed by the groups, since they are often unspoken, that will cause poor results in customer evaluations. By using a dis-satisfier analysis we can see if critical functions or features are forgotten, since the person quickly passes on the product.

In evaluations with the customers they were allowed to use the products, evaluate them in person and even contrast them, which is similar to the process experienced in the store. In performing this process of watching the customer use the product, critical knowledge is gained to guide the interview, focus group and remaining contextual analysis.

In performing individual interviews and focus groups a broad range of ages were used. The teams had used no demographic limitations in most of their reviews; it was critical to likewise use open demographic analysis. Teenage, college aged, mother, father, grandma and grandpa segments were interviewed. There were over 50 interviews performed.

3.4 Creating Value Score Metrics Based on Functionality Requirements

The modern value formula is: value = (performance + capability) / cost. This can also be written as value = function/cost. In this part of the results the above value formula was adapted by assessing the function focus DFSS and the cost focus of DFM. The goal was to assess from the created projects a healthier whole value function that employs a correct mix of both DFM and DFSS.

3.5 Apply Total Value Score

Having formally designed a value score using original value engineering definitions, and using a market analysis approach, a more complete Total value score system and Total value engineering path was created. This alters value/cost to a relative cost score, which is different than the procedure shown above. The basis was to create a Total Value Engineering structure to compare products across different market prices, different function and needs, as well as represents the critical DFM components of reduced cost to the customer for the functions given.

4 RESULTS AND ANALYSIS

4.1 Introduction

This section shows the analysis of the projects, the DFM and DFSS constructs, the contextual learning, and contrasts the results by using a total value score. Included are the key findings of the group analysis, group projects, value score results, and the combinatory process used to create a Total Value Engineering model.

4.2 Group Projects

The goal of each team was to improve DFM. Each group became focused on their learnings from Voice of the Customer processes within the DFSS construct and biased this towards new function designs over the original goal of part count and process cost reduction. Figure 3 shows the original flashlight and Figure 4 shows the new designed flashlights. Visually we see that the premise of DFM, maintain form and function, while reducing part and process count, was lost, as every flashlight looks significantly different than the original. Below is the breakdown of the significant different uses and functions.

Figure 3: Original Flashlight as Seen in Company Marketing Materials

Figure 4: Original Flashlight and Team Designed Flashlights

Each team worked off the assumption that people had used a flashlight before. They created House of Quality to evaluate which product features the customer would most value by creating scores and metrics, and interpreting that data to give critical decision factors of what pieces or ideas were most critical to attaining customer value. In analyzing many of the reports the groups largely performed low numbers of in-person surveys, and mostly used online questionnaires or open-ended responses that did not show the present flashlight that the project was based on. These errors in DFSS VoC application induced potential for survey and response bias.

The groups that did use in-person evaluations seemed to get a better idea of what the customer valued. This fundamental point played out heavily in the Contextual analysis below.

4.2.1 House of Quality

Analyzing the Voice of the Customer process of each team showed how they defined the market segment and demographics to be used. Each team recognized in general all segments were users of flashlights, and most teams left the demographic focus relatively general. Because the teams performed online surveys without visual quality of the product, the teams were given customer impressions of what they would like the products to have. This led to a critical component discussed below in the Kano section, where we see a heavy focus on satisfiers and a lower focus on dis-satisfiers. The most effective Voice of the Customer process is used, if the wrong demographic is interviewed, or the wrong responses are given, the results, metrics, and key determinants for design will miss other more needed functions that went unspoken. The problem was each team gathered large amounts of data for multiple groups and was the result of a poor House of Quality process. Because each group felt they had sufficient data to operate from, they accepted the responses they had received, without noticing that they had not performed contextual analysis, which is said to be the most critical part of capturing the voice of the customer. (Creveling, 2003) Below are two of the team's analysis of the market needs, the general criteria the market desired and the features that the market could use.

Table 1: Voice of the Customer Metric Scoring

	# of mentions / likes																					Sum	Weight
brightness	f	a	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p			19	
long battery life	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p	p			19	
adjustable brightness	f	f	f	f	f	f	s	a	p	p	p	p	p	p	p							15	
durable	f	f	s	s	a	a	p	p	p	p	p	p	p									13	
price	a	p	p	p	p	p	p	p	p	p	p	p	p									13	
Small size (ex: easily stored in jeans)	s	s	s	a	p	p	p	p	p	p												10	
Easy/simple to operate (battery replacement, mechanical adjustment)	f	f	f	a	a	f	f	f	s													9	
batteries charged when light needed ("immediacy")	f	f	f	f	f	f	s	a														8	
Light color (maybe a laser pointer?)	f	f	s	a	p	p																6	
light (not too heavy)	s	p	p	p	p	p																6	
Ease of locating light in dark / emergency situation (ex: glow in the dark)	f	f	s	s																		4	
doesn't need to be held with hands (potentially with mouth, tri-pod)	f	f	f	s	s	p	p															7	
waterproof / weatherproof	f	p	p	p																		4	
aesthetically pleasing	p	p	p	p																		4	
adjustable illumination area which stays bright	f	f	s																			3	
grippy/cushiony handle	s	s																				2	
not shining a headlamp right into someone's eyes	f																					1	
Bi-directional lens... (? we need more explanation on this)	s																					1	
Flexible lens	s																					1	
Turn off timer	s																					1	
no turn off timer	a																					1	
usable as bike light	a																					1	
LED bulb	a																					1	
toy / halloween	a																					1	
environmentally conscious design (no throw away portions)	p																					1	
Items	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**		
																						140	
													151										

Table 2: Voice of the Customer Metric Scoring Team 3

Question Asked:	**Average of Response: (1-5)**
Please rate the importance of the following characteristics in your ideal flashlight on a scale from 1-5 with 5 being the most important. [Brightness]	2.05
[Weight]	2.85
[Size]	2.4
[Cost]	2.75
[Aesthetics]	3.3
*[Durability]	2.3
*[Attachments]	3.65
*[Color]	3.5
*[Energy efficiency]	3.05
*[Battery type]	3
How much would you pay for ideal flashlight?	$30.56
What type of switch do you prefer to turn a flashlight on and off?	11 buttons, 5 switches, 2 twists, 1 squeeze
How long should a flashlight last?	7.74 years
How long is your ideal flashlight?	7.2 inches
How thick is your ideal flashlight?	1.59 inches
What color do you prefer your flashlight to be?	9 black, 4 silver, 3 red, 3 any color, 1 blue, 1 glow in the dark
*\How important is it for a flashlight to have a strap?	3.37
On a scale of 1-5 with 1 being I will only use flashlights that use incandescent light bulbs and 5 being I will only use flashlights with LEDs, where do you rank yourself?	3.32
What type of activities do you use a flashlight for?	Camping, home use, car, emergency, work, games, caves, reading.
How often do you use a flashlight?	at least once per week (5), at least once per month (5), several times a year (8)
What type of batteries do you use most in other household devices?	AA (16)
How long would you expect a $10 flashlight to last?	4.2 years
What is your age?	29 years old
Your gender?	52% male, 48% female
Have you seen our flashlight?	52% yes, 48% no
What do you like about this flashlight?	Its compact, the grip, bright, feels like good quality, looks good.
What would you change?	improve the strap, make flashlight longer
What do you think about the weight?	8/11 said it was about right.
What do you think about the brightness?	9/11 said it was about right.
How does the flashlight look? What do you like the most/least?	Compact and the color are good. too many grooves and overall shape is bad.
How does the flashlight feel? What do you like most/least?	good: solid, well balanced, good grip. bad: too small.
What do you think about the on/off button?	good: good location. bad: it's hard to push.
What do you think about the battery set up?	good: it's compact. bad: complex, battery size (AAA)
How much would you be willing to pay for a flashlight like this?	$9.65
How does this flashlight compare to others you've seen?	2.82

Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	AA Batteries	Between $5 and $10	Button switch	Button on the end	High and low beam setting	Handle is 1 inch in diameter	Handle is 3.5 inches long	Able to withstand a drop test	With batteries, weighs 6 to 12 ounces	High beam is between 40 and 60 lumens	Batteries last 24 to 36 hours on high beam	Lanyard is long enough to loop around the flashlight
3	11.1	4.0	Uses AA batteries	▲										O	
9	13.9	5.0	Low cost		▲				Θ	Θ	▲				
1	8.3	3.0	Button to turn on and off			▲									
3	5.6	2.0	Button on the bottom				▲				O				
9	5.6	2.0	High and low beam settings		Θ			▲						Θ	
9	11.1	4.0	Flashlight fills the hand		Θ				▲	▲					O
3	13.9	5.0	Flashlight feels durable						O	O	▲	▲			
9	11.1	4.0	Lights are as bright as possible		O							Θ	▲	▲	
3	11.1	4.0	Reliable battery life	O									O	▲	
3	8.3	3.0	Some way to attach or hang the flashlight		O										▲

Figure 5: Completed House of Quality Includes Valuation and Cost Metrics

4.2.2 Kano Model

Within the DFSS Voice of the Customer processes each group was analyzed on how well they met the Kano model requirements of recognizing the 3 function tiers: dis-satisfiers, variable and often spoken satisfiers, and exciting or delighters. The groups that did not understand DFSS experiments showed if a product is produced with the variables desired but a dis-satisfier is forgotten, the person will very quickly pass on the product. Because the groups didn't understand what things were actually dis-satisfiers, they made function mistakes that were so critical to some customers they said “Nope I wouldn’t buy it.” in less than 1 second of looking at it. At first the response of the people seemed strange, but after multiple respondents were quick to say similar things, further analysis showed people had natural inclinations of what a flashlight should have, this was the dis-satisfiers, and when groups missed it, it was instantly a fail with the customer. It was as if you were offered a car with auto-brakes or car-crash detection (satisfiers or even exciters), but you still wouldn’t buy the car if it didn’t offer doors to get in, and you had to climb through the sun-roof.

By allowing all the customers to experience the product, data was gathered that are naturally unspoken required functions, which are not mentioned by the customers in open-ended survey responses online, because the customer expects these things to already be included. (Creveling, 2003) It becomes the nature of users, when a product has certain features to expect those features and then overly mention new features or other things that would be expected. As said above, we don’t think to mention, the car needs an engine, or wheels; it is already expected.

4.2.3 Team DFM Analysis of Part and Process Improvement

Each DFM construct was analyzed to see if there were significant errors that occurred in DFM processes as was seen in DFSS House of Quality dis-satisfier results shown above. Each team performed dimensional analysis and part count analysis as well as material selection. Because the original flashlight has so many parts, it was a great project to use even if DFM was the only goal of the value increase, by reducing part cost and assembly time. Refer to the Figures 6, 7, and 8 to see the blown-out original flashlight to see the excess number of parts. In analyzing the groups, many of the groups were able to take the flashlight which had 35 parts, all the way down to 4 in their new designs. Many of the groups listed connectors, spacers, separators, excessing casing and other unneeded plastic pieces that could be easily removed while keeping the same form and function of the original flashlight.

Figure 6: Exploded View of Entire Original Flashlight (Orange Version)

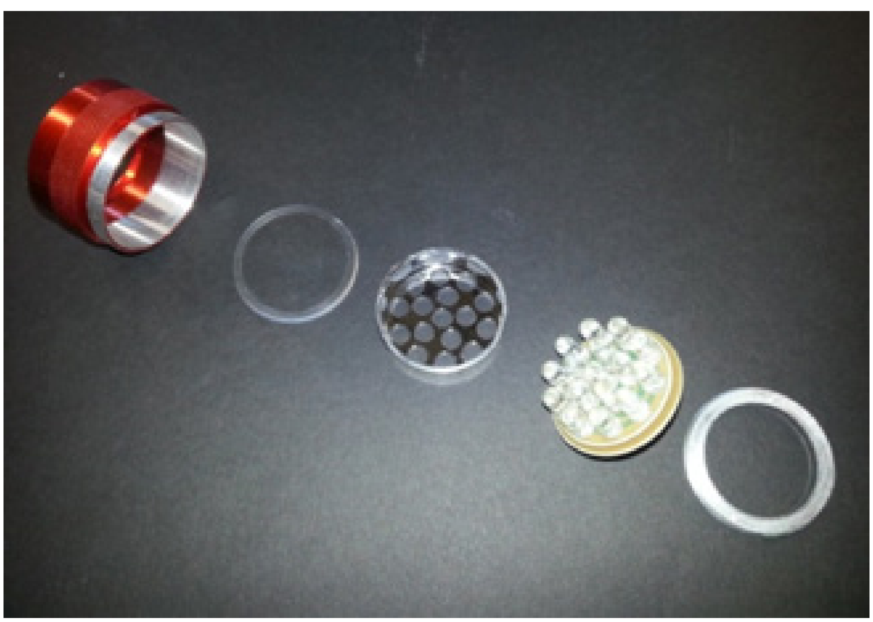

Figure 7: Exploded View of Lens and Light

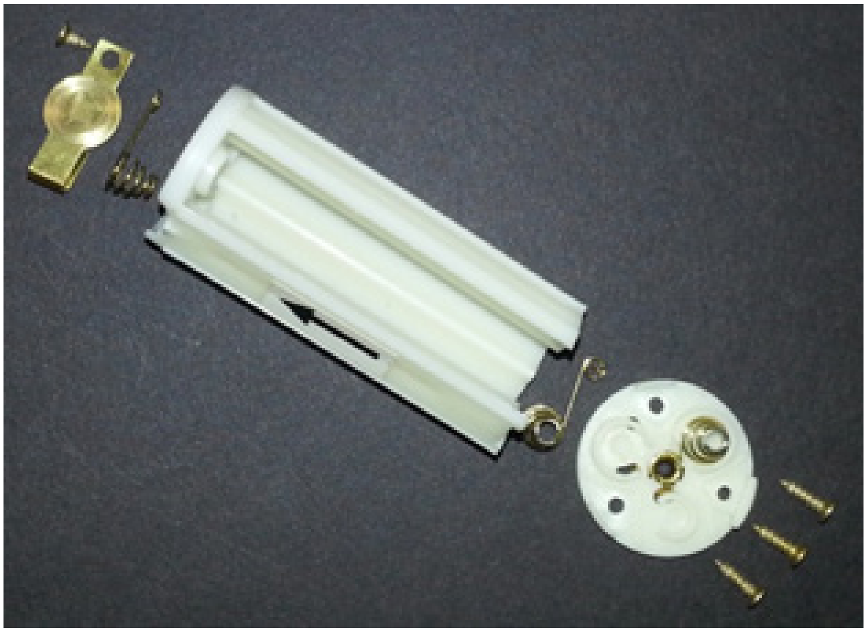

Figure 8: Exploded View of Battery Compartment

The teams understood the key principles of DFM. Their axis analyses for assembly times are in Appendix B. They contrasted whether the old flashlight could be made cheaper using manual or automatic assembly, while also recognizing part changes, part reductions, and manufacturing processes that could reduce cost and time while maintaining form and function. Placed in the appendix are many of the tables that were created to contrast the time, costs, and other variables that they took into account before they created their new prototypes and decided on which materials and processes to use.

Below, in Tables 3 through 9 are displayed the critical results of their analysis in cost reduction, part count reduction, and assembly time reduction. As noted above, many of the process and part changes they performed DFM analysis on are included in the appendix to give a fuller view of those steps as they performed them. In essence each group had significant part reduction, which would be the aims of DFM, if the final product had maintained the same form and function. The tables below show the success of their efforts in reducing the key DFM focuses.

Table 3: Dot Light Breakdown of DFM Improvements

Value Category	Dot	% Improvement
MFG Cost Original		
MFG Cost new	$ 0.08	
New Retail Target Price	$ 0.25	
Part Count Original	34	
Part Count New	5	85%
Assembly Time (sec), Original	157.7	
Assembly Time (sec), New	25.1	84%

Table 4: Aluminum Light Breakdown of DFM Improvements

Value Category	Aluminum	% Improvement
MFG Cost Original	$ 6.58	
MFG Cost new	$ 2.03	69%
New Retail Target Price	$ 10.00	
Part Count Original	35	
Part Count New	7	80%
Assembly Time (sec), Original	223.6	
Assembly Time (sec), New	3.8	98%

Table 5: Flex Light Breakdown of DFM Improvements

Value Category	Flex	% Improvement
MFG Cost Original	$ 4.03	
MFG Cost new	$ 0.99	75%
New Retail Target Price	$ 10.00	
Part Count Original	48	
Part Count New	9	81%
Assembly Time (sec), Original	362.3	
Assembly Time (sec), New	28.3	92%

Table 6: Side-Load Light Breakdown of DFM Improvements

Value Category	Side-load	% Improvement
MFG Cost Original	$ 7.05	
MFG Cost new	$ 0.94	
New Retail Target Price	$ 10.00	87%
Part Count Original	19	
Part Count New	8	58%
Assembly Time (sec), Original	254.4	
Assembly Time (sec), New	22.6	91%

Table 7: Hex Light Breakdown of DFM Improvements

Value Category	Hex Light	% Improvement
MFG Cost Original	$ 1.06	
MFG Cost new	$ 0.08	
New Retail Target Price	$ 10.00	92%
Part Count Original	32	
Part Count New	9	72%
Assembly Time (sec), Original	190.8	
Assembly Time (sec), New	31.5	84%

Table 8: Cube Light Breakdown of DFM Improvements

Value Category	Cube	% Improvement
MFG Cost Original	$ 1.40	
MFG Cost new	$ 0.41	71%
New Retail Target Price	$ 10.00	
Part Count Original	21	
Part Count New	8	62%
Assembly Time (sec), Original	131.0	
Assembly Time (sec), New	42.2	68%

Table 9: Total DFM Contrast on Prototypes

Prototype:	Dot	Aluminum	Flex	Side-load	Hex Light	Cube	Average
Mfg. Cost % Improvement:		69%	75%	87%	92%	71%	78%
Part Count % Reduction:	85%	80%	81%	58%	72%	62%	74%
Assembly Time %Reduction	84%	98%	92%	91%	84%	68%	89%

4.3 Contextual Analysis

In the 56 focus and individual group interviews performed we saw how people interacted with the products. Teams believed they had made a better product than the original flashlight. In reality, the results proved many of the groups had reduced value by their errant introductions of feature change with incorrect House of Quality application.

By allowing the interviewees contextual analysis of holding, seeing, thinking about the products uses, many of the products were noted by customers as shortsighted in key dis-satisfiers. Some of these products were dismissed before even given a second chance, as noted above, because they glaringly lacked a dis-satisfier.

In giving contextual experience, the customers had held and envisioned whether they would use the product or buy it. They were explained how the product would function if the light was working (since some were not working), and were asked to look beyond some defects like caps falling off or parts loosening.

For all products except for the dot light the customer assumed the light brightness was the same since they had all used the original flashlights 16 LED lumen brightness before seeing the other products. Since some required explanation of how to use, I did show how to twist the dot light, the cube and the aluminum light. They were shown how to straighten the flex light and how to press the button for the hex light and input the battery for the side-load.

By interviewing each individual and receiving a rating metric off of critical functions the customer desired, independent function scores were given for each product. The function score was generated by taking their preferences and accounting for the 3 tiers mentioned in the Kano model, and then giving the flashlight an overall purchase likelihood score. See Table 10 below.

The overall value score adds together the performance and capability with an average across the interviews, divided by the cost to the consumer for that product. The overall value score created by accounting for top-line performance is the most effective tool to compare products from different price categories. Because the rest of the products were priced comparably with the original flashlight, they can be compared based on the value ratio as well.

A perfect 1.00 value score qualifies as perfect function needs met individually and collectively across every aspect of the flashlight. This would mean all customers loved the individual feature offerings and gave the overall purchase priority score of 10, meaning they would desire to buy it over a typical flashlight they presently find in the store. Any number lower shows a decrease in desire to purchase in one or many function areas that they defined. The lowest score possible would be .1 for overall value score based off the rating system used. Any product that scored under .5 would be unlikely to be chosen in any circumstances where another option as a flashlight was given. In Table 10 below is included the overall value score and value ratio that was attained for each product.

Table 10: Value Scores for Prototypes and Original Flashlight

Prototype:	Dot	Aluminum	Flex	Side-load	Hex Light	Cube	Original Flashlight
Overall Value score	.920	.843	.217	.433	.529	.629	.943
Cost $	1	10	10	1	10	10	10
Value ratio	.920	.0843	.0217	.0433	.0529	.0629	.0943

All the groups had listed their products at the sales price of $10, except for the dot light which was listed as 3 or 4 dot lights for $1. Some products did mediocre with some groups but quite well with others. If it was not for some adult males who did not want the aluminum light, it would have scored similar to the dot light. The aluminum flashlight scored well with younger women and older women and older men, but they all struggled slightly with the idea of turning on the light, by some other process than a button. The aluminum light creates the contact when the top plastic is pushed down to create the circuit. Without a button it just wasn't quite right to some of them, and even if I explained them the process, they were still unsure how much they would like having to push it down in the dark, rather than push a button (even though in my opinion it would be easier). The fathers said they typically leave a flashlight visible in their car or truck, which made metal a horrible choice according to them because of the dis-satisfier "it would get too hot from the sun." In this way, some of the products were given different dis-satisfiers based off different demographics, which caused a score reduction two function areas to affect the function value rating process. Other products tested poorly across multiple function areas, or even received the "Nope I wouldn't buy that" response before they had even held it or looked at it.

The flex light and the side load, both got a lot of novelty mentions, but these products designers attempts to create "exciters" as titled by the Kano model, missed the critical "dis-satisfiers". The awkward shapes and size or concerns of how to hold these products, and their significant difference from typical flashlights in turning them on made them rejected quickly in almost every single interview. The white hexagon shape didn't do well, although it had a critical thing that most people liked, a button, but the strange shape was often a dis-satisfier because it was uncomfortable. In reviewing the analysis of all 6 of the groups, very few even noted the necessity of comfort, because it was a natural dis-satisfier that people expect out of a flashlight. In actual post-prototype interviews, comfort was commented about, and ease of finding how to turn on in the dark, were peoples biggest worries, even more so than whether it was the brightest once it turned on.

The dot light grew a great deal of attraction because the small size and it's use of adhesive on the bottom to stick to almost any surface; most people immediately listed little things they would put them in (specifically for grandmas Christmas houses, to places in the car, to bedroom, etc.). The small side load and cube both often received dis-satisfier reactions because of the size and ease to lose the products. For the dot light, the size was not a dis-satisfier that they might lose it, because the price, but because of its stickiness and small size it actually became an "exciter." Interestingly the hexagon fared better with some interviewees because they did like the strap, which is one thing included in the original flashlight, which from most engineers viewpoint seemed pointless. But, in value score understanding, and new function creation the customer's wants are what truly matter.

4.4 DFSS Contrasted with DFM Results

From the results above, consensus can be made that DFSS has risks. The data show combining DFM and DFSS constructs properly can protect against the poor results some of these prototypes scored due to overly applying DFSS new function design thinking. There is also potential to overly value DFSS functions to be added and with a decrease in part-count increase the potential risk of missing critical functions. Some teams focused on part count reduction by as much as 85percent, which is an inherent risk that you will lose critical functions. It is like doctors stating 85% of the organs and joints and connective tissue in our bodies is unneeded, they may be right but the risk is there if you remove it.

The analysis does not prove there is no need to reinvent the wheel, even if the new models scored worse than the original. Instead the data shows the risk of trying to add product functions while removing key dis-satisfiers. Results show a company must be able to guarantee protection against missing the unspoken wants or expectations customers already have.

With the original flashlights sleek appearance (especially in grey), its nice hand held plastic grip, and many features that groups left off in their desire to create new functions, we see the misapplication of DFSS to the detriment of potential DFM learning. The teams had the potential to create flashlights that were very similar to the original using cheaper process and material as they outlined (refer to Appendix A).

In using a combined construct of DFM and DFSS, you exacerbate the risk if the process is not handled correctly, because if you have the intentions to heavily reduce part-count and then use the limited part-count to include new functionality, the likelihood of removing dis-satisfiers is increased.

Instead of getting the best of DFSS and DFM to create a more complete Total Value Engineering result, we see that groups who overly focused on using novel functions, with limited market knowledge and limited contextual analysis to know whether the form and function they were creating would be wanted, created a potential financial disaster.

For this reason, history is full of 2 types of thinking, either “don’t change it if it isn’t broken”, or the old VCR remote idea, “let’s just add in every feature possible.” The lesson is not to blindly apply DFM forever, and it’s not to just add in limitless new feature sets using DFSS as noted in the VCR remote example: cost and complexity eventually make this also a burden for most products and customers.

Meanwhile, we know that with each step of new product design, costs rise dramatically, and if they had gone to production, such a market miss, could be disastrous to a young firm. (Connor, 2011) The histories are full of novel ideas that never sold. The critical element of this analysis is when we gain understanding of the things that led heaviest to failure.

One issue was the nature of teams to let their own design bias and function ideas impede correct DFSS application. The groups' results show the tendency to lean towards over-valuing the DFSS "new ideas" while under-valuing the potential stability of prior functions and processes that were developed using prior or present DFM processes. For some reason, human nature of wanting the new can cause us to forget why the old worked.

To protect against over-valuing your own creative processes teams must incorporate iterative design processes and heavy contextual analysis. This has been noted by other companies as the most effective way to use DFSS in the marketplace (Creveling, 2003). Lots of DFSS tools focus on iterative, customer experience prototyping and even DOE processes which lead to re-inclusion or maintaining critical features. (Creveling, 2003)

If we incorporate a system of DFSS with effective pre-idea, post-idea, and post-prototype iterative processes we can limit the potential risk of function value errors. But as was shown with the potential for continual process and part-cost improvement, we need to have a DFM process included. There is no need to let cost improvement opportunities go un-noticed, as Ford showed, sometimes these efforts at cost improvement led to occasional minor function improvement that would not be found otherwise. (Ford, 1922)

4.5 Discussion to Create Total Value Engineering Model

In order to complete Total Value Engineering, it becomes necessary for DFSS to be used in a controlled process with DFM. It was the misapplication of DFSS that exacerbated the risk of part reduction techniques from DFM. Companies should first master division management using DFM principles. By continually placing all the divisions focus upon process and part improvement we can keep DFM thinking continually in front of the engineers that best know the present process (this is similar to how Ford operated).

If the company has a clear understanding of the present group technology, the present dis-satisfiers, the present market needs, only then are they ready to begin the risk of applying the second construct, DFSS. As noted above in the literature review, but needing to be clarified here for a more complete view of how to construct Total Value Engineering, when Sloan took over GM, some divisions were effectively applying product and process cost reduction techniques. Over time he learned that the same people who maintained the present process improvement practices were not the best people to oversee the larger "kaikaku" type changes. He decided to implement committees who worked on novel ideas, which if completed could be tested and worked in with the divisions if the division heads felt it would meet the market wants. (Sloan, 1964)

Originally they overshot the market desires with some of their large scale function improvements, but over-time by increasing awareness of where the market is at and where it is going, they were able to build a more complete value engineering proposition, minimizing cost while finding continual function improvements. In today's DFM system we have even more effective tools to maintain group knowledge, organize process and cost reduction than Sloan ever could. But at the same time, with the modern DFSS tools we have more effective processes to recognize the market direction and functions that will increase value than Sloan ever did.

As noted throughout the thesis, companies' goals should be to protect the company from disruptive innovations that take your market when you are not prepared for function improvements, but as we saw from the data incorrectly applying DFSS too early will lead to even more disastrous results.

To protect against these two system issues, it is most effective to incorporate DFM within all production divisions because it protects against function change occurring too quickly. As they increase present market understanding, a separate committee should be created to build off function needs using DFSS, as Sloan realized with his design improvement process. (Sloan, 1964) As the DFSS processes are performed to understand the Voice of the Customer, the actual production divisions will continue operating as usual. At this point where novel ideas or functions are desired, it is paramount that critical DFM engineers from that specific product division are included in DFSS function committees. The VoC and HoQ will be performed by individuals with that specific skill in mind who are not biased by the DFM process, so that all potential novel ideas can be discovered, but then in the new design process, the DFM engineers will have power to influence or stop certain functions from replacing key dis-satisfiers. By this structure the company will apply the key learnings from this case study, and coordinate the best of cost and process reduction with the best of function improvement. Naturally markets that are moving at a quicker pace will have created a DFM culture that expects change to come in, but will still be guarded against glaring errors through the DFM protections in place. This case study and process as outlined here shows a Total Value Engineering construct properly performed can achieve a better value ratio than either process could alone, by incorporating function improvement with the restraint of cost reduction.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The following 3 hypotheses were evaluated:

1) *Using a combined DFM and DFSS construct creates a more complete design approach and has potential to achieve higher value scores than either construct could alone.* From the data shown the teams did recognize potential improvements in part reduction as well as potential improvements in function. Although the teams did not achieve an overall better value score than the original flashlight because of the misapplications of the total value engineering construct, both processes show if they were each performed separately and then combined correctly a higher score would be achieved.
2) *Over-reliance on either the DFM or DFSS results can blind a company to not properly combine the two constructs.* In the team projects, each ended up focusing with excitement on their novel ideas, which led to a devaluing of other critical DFSS and DFM features. The results showed teams were blinded by aspects of either DFM or DFSS and forgot to properly apply both constructs. By using the Total Value Engineering framework explained in section 5.2 (summary) the teams can protect against misapplication of either framework.

3) *Using DFSS too aggressively can cause the company to forget key dis-satisfiers that must be present in the design.* The case study showed each group became fascinated with their novel functions to the point it caused serious errors in design of the final prototype. Almost every group left simple dis-satisfiers off the final product, even though the original product had these dis-satisfiers already included. If a company keeps focused on the often unspoken functions the customer expects, they are more likely to protect against missing these functions that will end up being critical to the viability of the product.

5.2 Summary

Using contextual and survey analysis to contrast DFSS and DFM in order to see insights into their strengths and weaknesses revealed these systems have different definitions of what creates value and this causes the users of these constructs to focus differently on how to improve value. Originally value engineering was created with a focus on maintaining function while reducing cost. The modern value formula is: value = (performance + capability) / cost or value = function/cost. As can be seen, this modern value definition allows for two different focuses, either increase value by reducing cost, or increase value by changing function.

Modern manufacturers are driven to compete in a more international and interconnected system, which has pushed many manufacturers to aim for decreased process times, improved quality, and reduction of manufacturing defects.

The DFM and DFSS analysis in this thesis showed the need for DFSS to protect against "disruptive innovators" (Christensen, 2013) but also a clear need for DFM principles to tightly control that process.

The research exposed the inherent nature for teams or companies, when taking on a mixed construct of DFM and DFSS, to over-apply one over the other to the detriment of the final product. By recognizing the human potential to over-design when using DFSS without sufficient controls the new framework created from these thesis results will help an organization protect against this result.

The research showed that a company who continues to implement DFM principles and maintain feature set over long periods of time is more likely to maintain higher value scores over companies who misapply DFSS. The largest causes of DFSS misapplication proved to be removal of critical dis-satisfiers.

DFM alone can be effective for a slow-changing market with cost reduction focus, and DFSS is effective for analyzing continually changing product and process designs, like a processor or software app marketplace. But the majority of industries and niches are not as clear-cut in their rates of growth as the microprocessor industry: many see periods of function constancy offset by unexpected function disruption. This disruption, by over-designing new functions from misapplication of DFSS, or not making sufficient changes because you are continually DFM focused, is the issue the new Total Value Engineering construct wishes to protect against.

Using a newly defined value score system to oversee the end prototypes . This new construct protects against the results seen in the team performance with over-design of new features while leaving off critical dis-satisfiers (features that customers naturally expect in the product).

The new Total Value Engineering system recognizes the risks of both systems, and builds in protection against the errors of each. Because DFM is established based off proven group technology, proven process and part reduction and settled assembly and product assessment techniques, it is the system that must be implemented first in the organization. Companies that do not know what critical functions and features they are already using is at the greatest risk to introduce new features that will remove critical dis-satisfiers. By using a standards framework like DFM, the company can control its production technology, process, and cost improvement methods. This allows them to effectively use the best wheel technology available, before trying to invent a better wheel. I cannot overstate how dangerous implementation of DFSS too early in an organization can seem to be. In the results above, if the teams really understood the flashlight industry, we would not have seen such aggressive function changes, and would have been protected from over-application of DFSS design change data.

After the company has established the product based off current function requirements of the industry and is achieving success at cost, material and process reduction while maintaining form and function, and is increasing profitability using these DFM tactics, only then, is it wise for a company to begin implementing DFSS function enhancement methods. There are some fast growth industries where some will not want to learn all the technology that is working up till present, but desire to disrupt with a macro-function change. From the research companies that over-apply DFSS too early increase the risk of missing the market, and the losses from DFSS function errors are far more costly than it is worth.

It is in creating a process for DFM implementation first, having an organization that truly understands the product they make, what the market is producing, and how to use group technology to reduce part and process while maintaining function that companies arrive at the sweet spot of opportunity to apply the DFSS construct effectively. Without the rigid controls of DFM in place, the inherent bias of human nature will lead to over-valuing “exciters” and forgetting some "dis-satisfiers" and making huge errors in the product. (Creveling, 2003) The cost to redesign is so heavy that companies who do not follow the process outlined take huge risks. As DFM is adhered to properly, and the company has proven itself competent at these cost and process reduction techniques, they are now ready to begin the full implementation of Total Value Engineering.

A DFSS committee can be created to work on function improvement, in a completely separate body of individuals. It may be wise to bring in 2-3 individuals most familiar with the technology improvements and critical functions from the division to counterbalance and be a springboard for the DFSS committee. The DFSS committee takes into account all critical functions (dis-satisfiers) as the present production division sees it. Meanwhile, the DFM division continues to function making continual improvements on the present product and process as if no DFSS research was occurring. The goal is to maintain a cost reduction, so that the company maximizes production value. After the DFSS committee has performed contextual analysis with the company's present product, and has gained critical insights from customers and performed other needed HoQ steps, they then return to discuss with the lead DFM engineer over that product, or the group of individuals chosen to best understand the product, in order to assess the DFSS design improvement learning with the current understanding of the lead DFM production engineers. This separate process of DFSS analysis by design creative allows them to increase the number of ideas whereas if performed by the DFM engineer his own bias to the way things are may undermine the effectiveness of the DFSS process.

These two sides go through rounds of discussions regarding function and features, as well as cost and production processes. At this point the DFM leads and DFSS committee should feel comfortable to begin prototyping a new product. After the prototypes are created the product should be tested using contextual analysis. The individual function and totality function evaluation which was created with discussions of the customer, as explained further in above research sections, should give insights if changes need to occur. The new prototype should always be tested in comparison with the present product the company produces. If the new product achieves higher value scores, then the company can continue on with production of the product. In short, this is the Total Value Engineering construct, which if effectively applied, companies can maintain a market lead in cost and process reduction, while as well be a leader in function advancement. Companies who successfully apply this model will certainly out perform a company who applied only DFM or DFSS alone.

5.3 Discussion of Learnings

This research shows why companies tend to apply DFSS more heavily in today's fast moving international marketplace over DFM which is more focused on time-tested practices. This research also showed potential biases that creep into companies as they choose to make DFSS or any other function improvement construct their primary design process.

It is apparent through this research, the group projects, and analysis of Ford and Sloan theories alongside DFM and DFSS, that a construct that uses both value aspects of increased function and decreased cost with effective constraints will be useful in the marketplace.

5.4 Recommendations

This research, rather than answering all the variables within DFSS and DFM constructs, shows a need for further analysis. We were only able to test this research on one industry and contrast it to known data, but this research would need to be applied on multiple industries, some that have experienced slow change, no change in function (like TV remotes) and markets that are heavily evolving. Since the prototypes created using the class DFM and DFSS combined construct obtained lower value scores than the market established flashlight, due in large part to ineffective Voice of the Customer processes, the new Total Value Engineering framework given in the summary should be applied with the exact same flashlight scenario, to see if higher value scores would be achieved. As noted, the new system properly incorporates contextual analysis early in the DFSS construct, which limits the likelihood for function over-enhancement. For this reason it is recommended that further research is performed using the new framework as outlined above given its DFM controls against DFSS errors.

If the new framework proves to obtain higher value scores in the team analysis mentioned, it would be advisable to apply this framework in industry. The second recommendation would be for a company that already implements DFM and/or has effective cost reduction and process improvement controls, to test the DFSS integration process as noted above to see if the new construct as created herein for Total Value Engineering, would increase their actual market success and their own market value scoring process.

It may also be valuable to perform company analysis on past eras where companies implemented design and product improvement based on these two design constructs of either cost reduction or function improvement, and then contrast that to the market results.

The potential for error in application on fast growth markets is higher given the nature of DFSS risks over DFM. For this reason it is recommended this new Total Value Engineering framework be applied in multiple industries to get a clear picture of its effectiveness in a fast changing industry like a cell phone, or application (app) software space, as well as a slower industry like the flashlight.

The use of one flashlight as the basis for comparison made creating a value ratio for contrast, easier, but may still be insufficient to give correct ratios on these products. I would advise that if the teams do find success in applying this new framework in the classroom with the same flashlight that multiple flashlights are used as a baseline to see if multiple original data points can enhance the DFM or DFSS aspects in the new framework.

All of these recommendations are given, only in the hopes that future studies can be done, in order to further test the Total Value Engineering framework.

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APPENDICES

APPENDIX A: TEAM'S ORIGINAL FLASHLIGHT ANALYSES

Grip assembly analysis

Depression 1	Depression 2	Uniform Wall	Uniform Cross Section	Axis of Rotation	Regular Cross Section	Captured Cavity	Draft	Enclosed Cavity
Yes	No	No	No	Yes	Yes	No	No	No

	Current State	***Option 1***	***Option 2***
Material	Polyurethane (assumed)	Silicone	Polyurethane Foam
Manufacturing Process	Injection Molding	Polymer Casting	Foam Molding
Material Cost	$127,260.00	$270,000.00	$15,840.00
Manufacturing Cost	$108,240.00	$50,000	$48,000
Total Cost	$235,500.00	$320,000	$63,840

Lens Analysis

Depression 1	Depression2	Uniform Wall	Uniform Cross Section	Axis of Rotation	Regular Cross Section	Captured Cavity	Draft	Enclosed Cavity
No	No	No	No	Yes	Yes	No	No	No

	Current State	***Option 1***	***Option 2***
Material	Acrylic (assumed)	Polyethylene	Soda Lime Glass
Manufacturing Process	Injection Molding	Thermoforming	Injection Molding
Material Cost	$5,515.46	$2,812.88	$7,728.36
Manufacturing Cost	$881.48	$2,333.33	$1,037.04
Total Cost	$6,396.94	$5,146.22	$8,766.40

Casing analysis

Depression 1	**Depression2**	**Uniform Wall**	**Uniform Cross Section**	**Axis of Rotation**	**Regular Cross Section**	**Captured Cavity**	**Draft**	**Enclosed Cavity**
Yes	**Yes**	**No**	**No**	**Yes**	**Yes**	**No**	**No**	**No**

Scale = 1-10	**Inexpensive (40%)**	**Lightweight (50%)**	**Durable (10%)**	**Overall Score**
Aluminum	4	5	6	4.7
Polyethylene	7	8	1	6.9
Epoxy	6	7	8	6.7

Manual assembly of current design

Item Name	# of items	manual handling code	Handling Time per items	Manual insertion Code	Insertion Time per items	Total operation time RPx(TH+TI)	Total operation Cost	Figure for min. parts		Labor Rate	Pay per second at $10/hr
No.	RP	HC	TH	IC	TI	TA	CA	NM	Description	$40.00	$0.01
1	1	10	1.5	00	1.5	3.00	$0.03	1	Body		
2	1	00	1.13	32	4	5.13	$0.06	0	Grip		
3	2	03	1.69	32	4	11.38	$0.13	0	O-Ring		
4	1	10	1.5	38	6	7.50	$0.08	0	End Cap		
5	1	10	1.5	34	6	7.50	$0.08	0	End Cap Plug		
6	1	35	2.73	32	4	6.73	$0.07	1	End Cap Battery Tab		
7	1	15	2.25	41	7.5	9.75	$0.11	0	End Cap Spring		
8	1	11	1.8	32	4	5.80	$0.06	0	End Cap Button		
9	1	10	1.5	00	1.5	3.00	$0.03	0	End Cap Button Cover		
10	1	13	2.06	00	1.5	3.56	$0.04	0	UPC Tag		
11	1	10	1.5	30	2	3.50	$0.04	0	Wrist Strap		
12	1	10	1.5	00	1.5	3.00	$0.03	0	Battery Holder		
13	1	10	1.5	00	1.5	3.00	$0.03	0	Battery Holder Top		
14	3	35	2.73	40	4.5	21.69	$0.24	0	Battery Holder Spring		
15	1	35	2.73	30	2	4.73	$0.05	0	Battery Holder Tab		
16	1	33	2.51	30	2	4.51	$0.05	0	Battery Holder Label		
17	3	11	1.8	39	8	29.40	$0.33	0	Screw		
18	3	10	1.5	06	5.5	21.00	$0.23	1	Battery		
19	1	10	1.5	39	8	9.50	$0.11	0	Front Adapter		
20	1	10	1.5	39	8	9.50	$0.11	0	Light Housing		
21	1	03	1.69	00	1.5	3.19	$0.04	0	Lens		
22	16	30	1.95	95	8	159.20	$1.77	1	LED Bulb		
23	1	10	1.5	00	1.5	3.00	$0.03	1	Reflector		
24	1	33	2.51	00	1.5	4.01	$0.04	1	LED PCA		
25	1	15	2.25	36	8	10.25	$0.11	1	Top Spring		
26	1	10	1.5	39	8	9.50	$0.11	0	Clamp Ring		
Total	**48**					**362.33**	**$4.03**	**7**			
Effeciency	5.80%										

Automatic Assembly Analysis of Current Design

Item No.	Name	Repeat count	Feed code	Orient efficiency (E)	Relative feeder cost (C_r)	Overall dimension in feed direction (L)	Max feed/minute (F_m)	Feeding cost (C_f)	Insertion code	Relative workhead cost (W_c)	Cost of standard workhead	Insertion cost (C_i)	Total cost (C_t)	Min parts
1	Body	1	22000	0.75	1	63.5	17.72	$0.05	00	1	$0.0006	$0.0009	$0.05	1
2	Grip	1	20010	0.9	3	39.1	34.53	$0.14	34	3.6	$0.0006	$0.0032	$0.14	0
3	O-Ring	2	00050	0.7	5	1.7	617.65	$0.01	32	1.6	$0.0006	$0.0014	$0.02	0
4	End Cap	1	11000	0.3	1	29	15.52	$0.05	38	0.8	$0.0006	$0.0007	$0.05	0
5	End Cap Plug	1	07400	0.1	1	20.6	7.28	$0.05	02	1.5	$0.0006	$0.0014	$0.05	0
6	End Cap Battery Tab	1	66446	0.15	6	19.3	11.66	$0.93	10	1.2	$0.0006	$0.0011	$0.93	0
7	End Cap Spring	1	11048	Manual Assembly Required									$0.11	1
8	End Cap Button	1	11000	0.3	1	8	56.25	$0.03	00	1	$0.0006	$0.0009	$0.03	0
9	End Cap Button Cover	1	02054	0.4	7	15.2	39.47	$0.32	34	3.6	$0.0006	$0.0032	$0.32	0
10	UPC Tag	1	74560	Manual Assembly Required									$0.04	0
11	Wrist Strap	1	79768	Manual Assembly Required									$0.04	0
12	Battery Holder	1	24044	0.85	5	49.3	25.86	$0.23	00	1	$0.0006	$0.0009	$0.23	0
13	Battery Holder Top	1	05000	0.5	1	22.9	32.75	$0.05	00	1	$0.0006	$0.0009	$0.05	0
14	Battery Holder Spring	3	17844	Manual Assembly Required									$0.24	0
15	Battery Holder Tab	1	66546	0.1	6.5	10.2	14.71	$0.29	41	2.1	$0.0006	$0.0019	$0.29	0
16	Battery Holder Label	1	79700	Manual Assembly Required									$0.05	0
17	Screw	3	21000	0.9	1	3.7	364.86	$0.00	38	0.8	$0.0006	$0.0007	$0.01	0
18	Battery	3	22000	Manual Assembly Required									$0.23	1
19	Front Adapter	1	12000	0.3	1	39.4	11.42	$0.05	38	0.8	$0.0006	$0.0007	$0.05	0
20	Light Housing	1	12000	0.3	1	39.4	11.42	$0.05	38	0.8	$0.0006	$0.0007	$0.05	0
21	Lens	1	00040	0.7	3	31.8	33.02	$0.14	00	1	$0.0006	$0.0009	$0.14	0
22	LED Bulb	16	21300	0.9	2	5.1	264.71	$0.01	00	1	$0.0006	$0.0009	$0.01	1
23	Reflector	1	08800	Manual Assembly Required									$0.03	1
24	LED PCA	1	08840	Manual Assembly Required									$0.04	1
25	Top Spring	1	20006	0.9	4	6.4	210.94	$0.03	36	1.4	$0.0006	$0.0013	$0.04	1
26	Clamp Ring	1	02000	0.4	1	34.3	17.49	$0.05	39	1.8	$0.0006	$0.0016	$0.05	0
												Total	**$3.25**	**7**

APPENDIX B: TEAM'S PROTOTYPE DFSS AND DFM ANALYSES

Voice of the Customer Analysis for New Design

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Able to withstand 10 drops	Use AA or AAA batteries	High luminosity	Low density material	Seals on openings	Low amount of pressure needed to turn it on.	LED	One handed on/off
				Column #	1	2	3	4	5	6	7	8
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	x	▲	▼	▲	x	x	x
1	9	16.7	8.0	Durable	Θ		▲		O		▲	
2	9	4.2	2.0	Standard Batteries		Θ					▲	
3	9	18.8	9.0	Brighter than cellphone		▲	Θ				Θ	
4	9	12.5	6.0	Light weight		▲		Θ			▲	
5	9	10.4	5.0	Water Resistant		▲		▲	Θ			
6	9	14.6	7.0	Button functionality (easy on/off)						Θ	▲	Θ
7	9	8.3	4.0	LEDs	▲	▲					Θ	▲
8	9	14.6	7.0	One-handed use		▲		▲		Θ		Θ
9												
10												
				Target or Limit Value	5 feet	<=2 batteries	>45 lumens	Less than 1/2 lb	Water resistant up to 3 ATM	<1 lb. pressure to turn on	White colored LED	One handed on/off
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)								
				Max Relationship Value in Column	9	9	9	9	9	9	9	9
				Weight / Importance	158.3	102.1	185.4	137.5	143.8	262.5	291.7	270.8
				Relative Weight	10.2	6.6	11.9	8.9	9.3	16.9	18.8	17.4

		Engineering Characteristics (how's) (1,3,9)														
		1	2	3	5	6	7	8	9	10	11	12	13	14	15	
Customer Requirement (What's)	**Weight (1-14)**	range of lumens output	granularity of light output adjustmen	minutes output at highest brightness setting	submergal	drop test height	melting temperatu of material	range of operating temperatu	Manufactu price ($)	Dimension (AxBxC)	weight (kg)	alternative charging method (y/n)	Customer review (aesthetics of ease of use)	Number of mounting options	Number of light colors	row
brightness	14	9		9					9						3	3.2
long battery life (per charge/use)	14	3		9				1	9							10.2
adjustable brightness	10	9	9	3					9							10.6
durable	9				3	9	9	9	9		1			1		0.625
Sales price	9	1	3	9		3	9	3	9	3	1	9		9		9.333
Small size (ex: easily stored in jeans)	7			3					1	9	1	1				0.167
batteries charged when light needed ("immediacy")	6	1		3					3			9				9.4
Easy/simple to operate (battery replacement, mechanical adjustment)	6	1			1				3	1		3	9			9.143
doesn't need to be held with hands (potentially with mouth, tri-pod)	5								1	1				9		9
light (not too heavy)	4			3	1	3	1		1	3	9			1		0
Light color (maybe a laser pointer?)	4			1					3						9	8.5
aesthetically pleasing	3		1				1		3	9	3	1	9	3	3	2.1
Ease of locating light in dark / emergency situation (ex: glow in the dark)	3								1	3	1	1				-1.4
waterproof / weatherproof	3				9				9	1						-2.25
adjustable illumination area which stays bright	2	9	1	1					3							0.6
Sum / relative importance of E.C.'s:		**297**	**122**	**420**	**64**	**120**	**169**	**122**	**613**	**152**	**73**	**166**	**81**	**148**	**87**	
Target Values		0-150 lumens	Infinite	120 min	yes	9 Ft	400 F	-30-140 F	$5	1x1x3"	.25 lb	yes	95% approval	3	3	
Threshold		0-50 lumens	3	20 min	yes	3 Ft	200 F	30-100 F	$10	2x2x4"	.5 lb	no	75% approval	0	0	

Cost of Assembly Analysis of Flashlight Prototype 4

Item Name	# of Items	Manual Handling Code	Handling Time Per Item, sec	Manual Insertion Code	Insertion Time Per Item, sec	Total Operation Time, sec	Figures For Min. Parts	Description
Flashlight body	1	10	1.5	00	1.5	3.00	1	Orient
LED assembly*	1	10	1.5	00	1.5	3.00	1	Drop in
Button cover	1	10	1.5	00	1.5	3.00	0	Press in
Button	1	30	1.95	30	2	3.95	0	Insert and fold
Button spring	1	10	1.5	03	3.5	5.00	0	Slide in
Button housing	1	10	1.5	01	2.5	4.00	0	Press in
Batteries	2	10	1.5	00	1.5	6.00	1	Drop in
End cap	1	10	1.5	30	2	3.50	1	Insert and twist
						31.45	seconds	
						$0.17	piece	

Orient Efficiency E	Relative Feeder Cost, Cr	Maximum Feed/Min Fm	Feeding Cost Cf	Insertion Code	Relative Workhead Cost, Wc	Insertion Cost, Ci	Total Cost, Ct	Minimum Parts
0.4	1	15.00	0.3	00	1	0.60	0.90	1
0.4	1	18.18	0.3	00	1	0.60	0.90	1
0.4	5	27.27	1.5	00	1	0.60	2.10	0
0.2	2	20.00	0.6	30	1.2	0.72	1.32	0
manual							0.28	0
manual							0.22	0
0.75	1	22.50	0.3	00	1	0.60	0.90	1
0.9	1	45.00	0.3	00	1	0.60	0.90	1
							7.52	
							$0.08	piece