IDETC/CIE Graduate Student Design Essay Competition 2018

The Future of High-Tech Global Manufacturing and Design

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Introduction

To whom it may concern,

I have been appointed to address your company's desire to position itself as the leader in global design and manufacturing by the year 2035. As a consultant for the company it is easy to see that you are currently a dominating force globally, but in order to preserve that foothold and ascend as the leader a deeper understanding of how the world will evolve in the coming years is imperative. Predictions about the world of 2035 present humanity with new challenges. In the realm of design and manufacturing the proliferation of automation, rising consumer classes, and the increasing awareness of the environment and sustainable issues will likely drive the direction of companies such as yours.

The level of automation present in current manufacturing processes presents companies with the conundrum of utilizing smarter manufacturing techniques while potentially propagating the issue of eliminating human employees. An informed and creative balance between automation and human resources could mitigate the hysteria of automation. The biggest worry currently being in the transportation industry, where millions of transport workers could be without work due to the rise of more intelligent self-driving systems [1]. By 2035, the possibility of complete human elimination from manufacturing processes can be seen in the automotive industry. Setting delays aside, Elon Musk's Tesla 3 manufacturing line is a glimpse into this reality; humans could be replaced entirely in the coming years if the technology becomes cheap and reliable. However, the rise in automation in manufacturing is not all gloom. Automated processes can lead to increased efficiencies, better product quality, and incorporation of increasingly complex product designs; opening the door for a wealth of possibilities in the global design and manufacturing industry.

The reduction of poverty on a global scale will lead to an increased number of global consumers. In his annual letter in 2014, philanthropist Bill Gates predicted that continued levels of foreign aid could eliminate poor countries by the year 2035 [2]. These new consumers will open the doors for your company to design and manufacture new products on a global scale. While providing research and experience in designing products in wide ranges of use-environments. This would give engineers the opportunity to study and understand untapped markets and how to best situate yourselves to bring more consumers into the global spectrum; alongside the markets your company currently resides in.

Another area of design and manufacturing to focus on in the coming years is the issue of sustainability and environmentally friendly practices. The turn of the century brought about an increased awareness of the environment and the human effects on it. Researching environmentally friendly practices and sustainable methods related to design and manufacturing would help situate your company as a global leader by 2035. Recent research into eco-literacy and consumption showed that the increased level of awareness in consumers about the environment caused them to favor products that were designed or advertised as sustainable over products whose impact is unclear [3]. Increasing worry about material waste, energy inefficiencies, and recyclability has driven a few companies to begin using more sustainable practices. The current leader in transitioning to this future is Apple; where they employ a closed-loop manufacturing system, renewable energy, and waste reduction techniques [4]. Adopting, researching, and evolving many of these practices would allow your company to achieve higher notoriety in the world of design and manufacturing.

The issues and changes facing your company from now into the year 2035 will not be solved or achieved by a catch all change. Instead, I propose that your company employ what are known as concurrent engineering techniques to smoothly transition into the world of 2035. The reasoning behind this proposal is that concurrent engineering is the ideal product development environment wherein the objective is to improve quality, reduce cost, reduce cycle times, increase productivity and efficiency, and improve social image [5]. This is achieved by breaking down a product's design into different areas of focus. The encompassing term for these areas is Design for X (DfX) and include subjects such as Design for Assembly (DfA), Design for Manufacturing (DfM), Design for the Environment (DfE), Design for Quality (DfQ) among other aspects of product design.

As many of you know, the design process follows the same relative principles found in Figure 1: identify a problem, research the problem, generate solutions, select the best solution, prototype, test the solution, present results, and redesign if necessary. The design process is also highly iterative, often requiring several redesigns to satisfy the constraints necessary in bringing the product into full scale production. Employing DfX knowledge into the design process could aid in eliminating the iterative nature by incorporating design knowledge earlier on in the design phase. This is crucial not only in increasing a company's efficiency towards ideating and manufacturing products quickly enough to satisfy the identified problem, but to do it in an intelligent manner that also satisfies consumer needs.

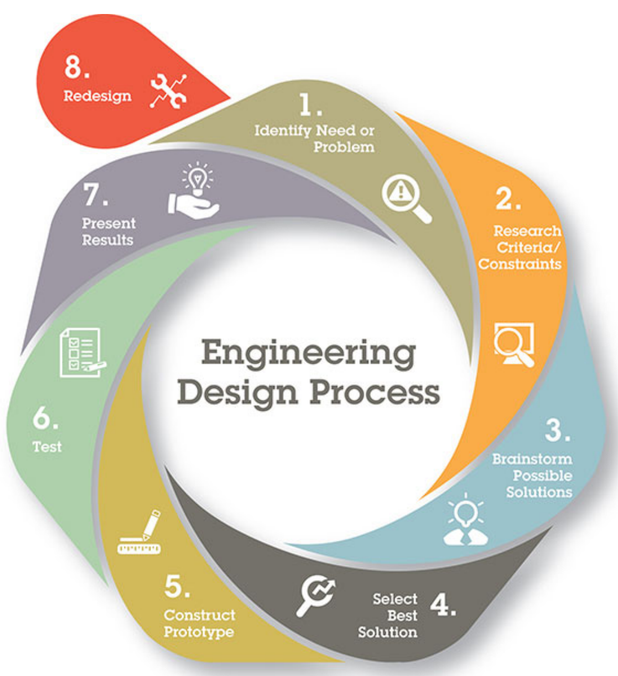

Figure 1. Design process flow diagram [6]

Arguments emphasizing the integration of DfX principles into the design and manufacturing process is not a new concept for manufacturing enterprises [7], so for the purpose of this proposal I wanted to focus on three key DfX areas, Design for Manufacturing and Assembly (DfMA), Design for Serviceability, Reliability, and Quality (DfSRQ), and Design for the Environment (DfE). I believe these three areas will be critical aspects of research and development for design and manufacturing companies to remain competitive on a global scale entering into 2035. The rest of this paper will outline an approach to achieve this goal, followed by describing the three DfX techniques your company should focus on by outlining the current state of the field and possible future states. Concluding with a summarized section of the directions your company should strive towards in the coming years to become a dominating force in global design and manufacturing.

Approach

Tackling these issues will involve building and fostering relationships with academia and private industries alike. However, a more intelligent way to advance the status of your company is to hire recent academic graduates or former employees of design firms that have experience in researching and implementing the concurrent engineering techniques discussed in this paper. This would allow for a baseline of necessary knowledge about the problems at hand to be inherently built into your company. The experience of these engineers playing a key role in successfully and efficiently fostering the implementation of modern design methods.

Design for Manufacturing and Assembly

Design for manufacturing and assembly (DfMA) is the practice of incorporating manufacturing and assembly knowledge into the design of a product in order to avoid unnecessary design changes stemming from the omission or disregard of available manufacturing and assembly technologies. The end goal of including this knowledge is to generate products that improve production costs, lead times, quality and product lifespan. Typically the manufacturing and assembly principles are incorporated into the design of a product in a way similar to the flow seen in Figure 2. The iterative cycle of design simplification and material choices can lead to the design following the Pareto Principle, where 80% of the time spent redesigning stems from 20% of the design itself [8]. Understanding and researching this area of the design process will better optimize the manufacturing and assembly phases of product development.

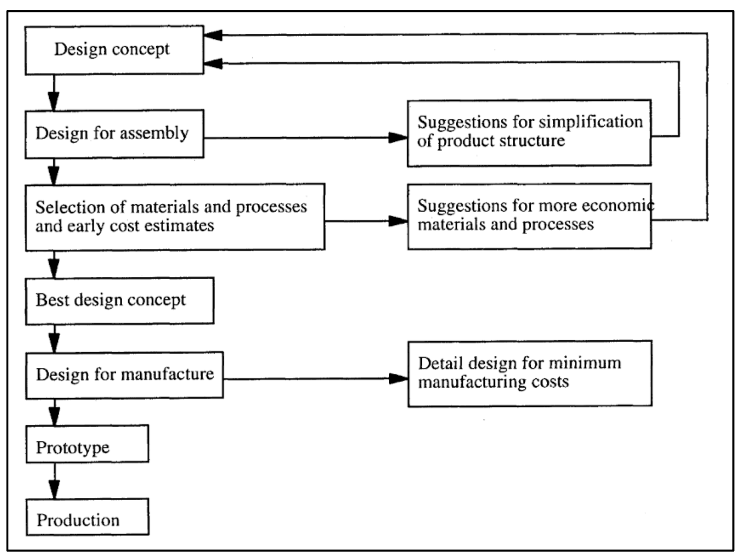

Figure 2. DFMA flow diagram [5]

Manufacturing and assembly in the current era involves the heavy integration of technology into existing or up-and-coming design and manufacturing processes. On the subject of design; design optimization is a research field involving the solving of design problems utilizing computational techniques. The underlying principles of optimization involve minimizing an objective function constrained by design requirements where both aspects are driven by design variables. A simple example of an optimization problem involves designing a table. The objective function could be anything from total material use to manufacturing time but for the interest of DfMA principles, we will use manufacturing time as the objective function. From there the constraint equations are defined; these can be anything from dimensions to material properties or manufacturing realities (E.G. is it necessary to have a titanium table and how expensive would this be to manufacture). The objective function and constraint equations are then evaluated using computational techniques like numerical methods, tree searches, or genetic algorithms until the objective function is optimized. The designer is then able to examine the combination of design variables and utilize this to create an optimized table.

Regarding DfMA principles, studies have shown that incorporating design optimization can lead to more efficient manufacturing [9] and even better exploration of design spaces [10]; resulting in better lead times and unconventional design solutions. Another study in optimization showed the use of an optimization technique known as Particle Swarm Optimization (PSO) that generated an optimum assembly sequence-planning (ASP) for product assembly [11]. This method would allow engineers to find the optimum assembly sequence of a potential designs and delegate resources for the manufacturing and assembly of that design accordingly.

Figure 3. Boeing 737 being assembled in an automated assembly system [12]

As mentioned before, the proliferation of automated assembly lines has reached a tipping point. In the aerospace industry, giants such as Boeing, Bombardier, Lockheed Martin and others have adopted assembly lines that are fully automated and interconnected [12]; Figure 3 showing Boeing's 737 Dreamliner in one of these automated assembly lines. These advancements have also led into research regarding the fine tuning of these assembly processes. One study proposing a computing and service-oriented manufacturing model that utilized cloud computing to enhance resource utilization while simultaneously reducing resource and energy consumption [13]. This study showing key advantages in resource utilization, up-front cost reductions, reduced infrastructure and administrative cost, efficient production scaling, exploration of new manufacturing models, and optimization of existing manufacturing methods.

Lastly, the emerging technology of virtual reality in computer aided design has taken hold in manufacturing and assembly research. The notion of combining the two has existed since the late 90's [14] but due to the hardware costs and software limitations didn't gain traction until recently. The most prominent area of use emerging in the automotive industry and showing promise in time-to-market reductions, quality enhancements and cost savings during the product development process [15]. One study showed the ability of these virtual reality systems to "improve user's confidence and speed when determining the feasibility of proposed design changes" [16]. This can be crucial for a designer to confidently integrate DfMA methods into a potential product by manipulating and understanding the system itself before it is prototyped.

Future research into the three areas of optimization, automation and virtual reality with respect to Design for Manufacturing and Assembly principles will be crucial in orienting your company as a global leader. The ability to optimize a design solution, understand that design using more interactive design spaces, and improve the manufacturing and assembly processes using more intelligent and connected systems will set you apart from other global design leaders.

Design for Serviceability, Reliability, and Quality

The life cycle of a product can be broken into three overarching segments: manufacturing, use-phase, and disposal. Design for Serviceability, Reliability, and Quality (DfSRQ) revolves around incorporating designs into products that make them inherently more reliable and easy to repair during their use-phase. This is critical in not only designing superior products but also satisfying consumer needs in relation to product life-span. Understanding how to incorporate higher quality and more reliable designs into products will ensure satisfaction in your current consumer markets and aid in capturing potential emerging markets globally.

Serviceability is the measure of ease and speed in which corrective or preventative maintenance can occur [17], designing for it involving streamlining repair times by reducing complicated repair processes. Designing for reliability involves utilizing physics-of-failure knowledge to design out potential problems related to a products design [18]. Design for quality generally follows the same principles as reliability but also incorporates customer experience; quality is sometimes in the eye of the beholder.

With the rise of interconnectedness on a global scale it is vital to design products that are reliable or easy to repair for the simple fact that repair chains in emerging markets might alienate consumers if they are unable to continue using said products. The easiest recognizable issue stemming from lack of DfSRQ within consumer products and goods arise in product defects, and can generate additional wastes due to overproduction, transportation, and excess processing [7]. Exploration into better understanding these waste flows has shown potential in creating less wasteful production system configurations and even facilitated better communication within a company [19]. Meaning that manufacturing and the necessity of communication at all stages of the process could be optimized. Analysis into the lifespan of different commodities showed promise in better understanding the use-phase duration of products but admonished the representativeness of the sample data [20]; oftentimes this data is difficult to accurately represent.

Future research into early design phase decisions and the downstream effects that these decisions have on a products serviceability, reliability, and quality will eliminate the need for designers to reiterate a design after an issue has been identified. With regards to product lifespans, utilizing more accurate data samples of product life-times could allow designers to better understand what product attributes increase reliability and then incorporate these into future designs. Developing optimization tools or automated design programs to more efficiently integrate DfSRQ lessons into future product designs will become an integral aspect of the design process. Analyzing the dynamic ranges of product environments can also aid in attempting to design goods that solve wide ranges of problems. Also understanding how products will be serviced or repaired in these environments is crucial in increasing product life spans. More in depth understandings of DfSRQ methods by 2035 will allow for seamless transitions into new markets and strengthen loyalty in existing consumers; allowing companies that design reliable products to gain status in the dynamic world of a global product's use-phase.

Design for the Environment

Since the turn of the 21st century the environment and humanity's effect on it has entered the forefront of many scientific studies and has since become a global issue. Most notably, the establishment of the Paris Agreements showing the worlds ever increasing desire behave more sustainable and environmentally friendly [21]. None of the DfX methods encapsulate every design aspect of a product more than Designing for the Environment (DfE), making it one of the most difficult but rewarding methods to fully integrate into product design. Sustainable products are "products that provide environmental, societal, and economic benefits while protecting social health and welfare, and maintaining the environment over their full life cycle from raw materials, extraction, and use, to eventual disposal and reuse" [22]. As mentioned previously the life cycle of a product encapsulates three general areas: manufacturing, use-phase, and disposal. Deeper understandings about the impacts of products require a more in-depth examination related to each of these three areas in order to properly implement DfE methods. Figure 4 shows a more detailed representation of areas that influence the environmental impact of a product [23]. Understanding the downstream environmental effects of design choices related to each of these areas will prove to be a vital paradigm shift entering into the word of 2035. Making the adoption and recognition of more sustainable design practices the highest priority of a design and manufacturing company wanting to gain global leadership.

Figure 4. Sustainable design parameters [23]

Research related to materials and DfE shows that the global extraction of resources has expanded remarkably since the 1980's and "a change in global production and consumption patterns will be necessary to achieve sustainable global development" [24]; this notion being aimed mostly at the wealthy consuming regions of the world. The effects of this can be seen in the rise of recycling programs [25] and research into repurposing of recycled materials [26]. Banning of certain materials or products can also be seen in the recent phasing-out of plastic straws in certain US cities [27]. All of this in the name of fostering a healthier environment.

The easiest identified environmental impact is in the way we dispose of things. Improper disposal of materials is often easy to see, India is a prime example of an improving nation still developing waste disposal techniques; Figure 5 showing an example of waste accumulation in Mumbai [28]. The climate of consumerism and the golden age of plastics spawned environmental tragedies such as the infamous accumulation of plastics within our oceans [29] and impacts due to solid waste landfilling [30]. There is however current work in better disposing of materials once a product has reached end-of-life. Apples interest in generating the first closed-loop supply chain [4] is the first step in creating a more sustainable end-of-life scenario for the everyday products we use. Proper labeling of the materials to improve recyclability is also becoming increasingly important to manufacturers and consumers alike but often found to be unsatisfied [31]. Sorting and recycling methods are improving but the need to further improve proper disposal of materials through design is imperative for proper implementation of DfE.

Figure 5. Human and solid waste accumulation in Mumbai [28]

Manufacturing research related to DfE is most notably seen in the rise of lean manufacturing practices. The reason being lean manufacturing often compliments sustainable design due to the objectives found in both. Reducing material waste, increasing energy efficiency, and minimizing lead and down time are all examples of the associated goals between the two. Studies on the implementation of lean manufacturing have shown that companies that adopt and expand these practices perform better than others and are constantly open to further refinement [32]. Lean manufacturing principles are so effective that it has also been implemented in the development of Plutonium 238 for uses in heat generation [33].

With regards to implementing more sustainable designs into products, Life Cycle Analyses (LCA) a few of the currently available tools that help engineers better understand a products impact upon the environment. These LCAs incorporate the different aspects of a product’s life cycle (Figure 4) and output quantifiable environmental impact data stemming from each area of the products life cycle. The data varies depending on the LCA utilized but some examples of the metrics include carbon emissions, land depletion, air acidification, and water eutrophication. Commercially available LCAs such as thinkstep GaBi, Eco-indicator 99, and SolidWorks Sustainability allow designers to analyze proposed design solutions, but they are not without their drawbacks. All of these tools require a products design to be relatively complete, making implementing more sustainable choices yet another iterative step within the design process. They also fail at instructing designers about more sustainable decisions, making them more calculators and less like advanced sustainable design tools.

Design tools that more efficiently incorporate DfE methods into product design will be the next research avenue for design companies striving to become global leaders. Further inquiry into sustainable and efficient material acquisition along with the adoption and evolution of lean manufacturing principles will become paramount in a leading design and manufacturing enterprise in 2035. Development of more advanced LCA tools that can incorporate more sustainable product design knowledge during the early phases of product development will also become an integral part of accelerating DfE methods becoming not just a design perk, but rather a design necessity.

Conclusions

For your company to become the primary leader in global design and manufacturing the proper implementation of concurrent engineering techniques is critical in gaining this position. These concurrent engineering techniques are subjects referred to as Design for X (DfX). More specifically, research and development into Design for Manufacturing and Assembly (DfMA), Design for Serviceability, Reliability, and Quality (DfSRQ), and Design for the Environment (DfE) will set your company apart from other globally competitive enterprises. The reason being that the notion of *designing for* something will eliminate the iterative nature of the design process and open up new avenues of exploration for engineers.

In the interest of DfMA, the integration of optimization techniques, advanced manufacturing, and more intelligent design spaces will aid in developing products that are easier to manufacture and assemble. For DfSRQ, understanding the downstream effect of design choices with regards to a products serviceability and life-span will help in fostering existing and potential consumer markets. The inevitability of humanity striving for a more sustainable future will implore the use of DfE methods to develop products that are inherently environmentally friendly. Combining and emphasizing these DfX methods will surely make your company the prevailing head of global manufacturing and design by the year 2035.

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