College of Engineering & Computational Sciences

Senior Design Trade Fair

MINES

November 20, 2014

Capstone Design Program
College of Engineering and Computational Sciences

COLORADO SCHOOL OF MINES
GOLDEN, COLORADO 80401-1887

A Special Word of Thanks to Our Judges

It is my pleasure to offer a personal welcome to the judges of the FAll 2014 Colorado School of Mines College of Engineering and Computational Sciences Trade Fair. We appreciate your willingness to take time from your normal activities to evaluate our senior's capstone design projects. The opportunity for our students to get feedback from experienced engineers is invaluable.

Senior design allows our students to demonstrate the engineering knowledge that they have spent four years acquiring. We encourage you to spend time with the design teams and to inquire about their projects and their designs. But also ask about their design process, because in the final analysis, senior design is as much about learning the process of design as it is about creating a design. As these students enter the workforce, it is their ability to use the design processes and methods that they have learned that will serve them most in their careers.

We are proud of our students and their accomplishments and hope you are equally impressed. If you would like to get more involved in our program, we are always in search of more project sponsors. Let us know!

Again, thank you and Happy Judging!

Kevin L. Moore
Dean, College of Engineering
& Computational Sciences

Capstone Design Program
College of Engineering & Computational Sciences
1500 Illinois St. • Golden, CO 80401
Design@mines.edu

Colorado School of Mines thanks the individuals and families listed below who have provided valuable support for our Senior Design students present today.

Program Sponsors

J. Don Thorson

Program Supporters

Al Cohen Family

Program Donors

-

Colorado School of Mines thanks the companies and organizations listed below who have provided valuable support for our Senior Design students present today.

Program Partners

Baker Hughes

Program Sponsors

Chevron

Shell Oil Company

Program Supporters

Phillips 66

Woodward Inc.

National Instruments*

Program Donors

Exxon Mobil

Holcim Inc.

ICAST Engineering

*Denotes donation of materials, services, or supplies to the program.

Sponsoring the Program

The Capstone Design Program provides Mines students with multidisciplinary, professional practice experiences as part of their education through Projects that Matter. The program relies on the generosity of our program sponsors. If you, or your organization, are interested in supporting the program please consider making a financial gift at giving.mines.edu. Your gift is tax deductible and will make a huge impact for our students.

PROGRAM PARTNERS	Donate $25,000 or greater
Your Funds will support the needs of many teams. In addition, partners will receive:	• An invitation to, and recognition at the beginning-of-semester Project Kickoff event (new in 2015). • All Sponsor, Supporter, and Donor benefits.

PROGRAM SPONSORS	Donate $10,000 - $24,999
Your funds will support the needs of multiple teams. In addition, sponsor will receive:	• An invitation to, and recognition at the end-of-semester Trade Fair event. • All Supporter and Donor benefits.

PROGRAM SUPPORTERS	Donate $5,000 - $9,999
Your funds will support the needs of a single team. In addition, supporter will receive:	• Recognition in all printed program promotional materials, on the College's website, and on signage in the Capstone Design Lab in the Brown Building Basement • All Donor benefits.

PROGRAM DONORS	Donate up to $4,999
Donors will receive:	• Recognition in the end-of-semester Trade Fair Program and a formal letter of thanks from the Mines Foundation.

Colorado School of Mines thanks the companies and organizations listed below who have served as clients for the student teams presenting today. Your donation of time, talent, and material support to our students is greatly appreciated.

Dan Novembre

Edge of Seven

Focus Tools, LLC

iDE

Lakota Outreach

United States Olympic Committee

Becoming a Client

The Capstone Design program in the College of Engineering and Computation Sciences (CECS) pushes students to go beyond their textbook training and solve real-world design problems. Every semester the college has over 50 student design teams who need great challenges to engage with. What opportunities does your organization have that could be addressed by a student team?

SUGGESTED DONATION	Corporate project sponsors are asked to provide a donation of $8,000 to the CSM Foundation. Up to $2,000 of that donation is made available to the student team for purchasing materials. The additional amount is used to support the program facilities, staff, and overhead.
TIME COMMITMENT	The involvement of the project sponsor is a key factor in the success of the project. Great project sponsors will commit one individual for approximately 1 hour per week to support the student team. In addition, any training or on-site resources that you can make available to the students are greatly appreciated.
OTHER	Student access to construction sites, manufacturing partners, or other company resources is always appreciated by the students.

PROFILE OF A GREAT PARTNER

The most successful industry partners share the following traits:

- View sponsoring a project as an outreach activity which helps train their junior engineers for management.
- Choose projects from their “nice-to-have” list and avoid having students on their critical path.
- Treat students like an entry-level engineer and plan on providing guidance throughout the process.

GETTING STARTED

Send an email to design@mines.edu to start exploring opportunities with program staff.

General Information Regarding Trade Fair

JUDGE'S AGENDA

Time	Description	Location
8:00 – 8:30	Registration	Brown Building West Atrium
8:30 – 11:00	Trade Fair Judging	Brown Building West Atrium

FINDING YOUR WAY AROUND

A floor plan and map of the Trade Fair is available on the back of this program for your convenience.

JUDGES LOUNGE

Snacks and beverages are available for judges in the Judges Lounge in Brown Building W250, just off of the atrium. Please feel free to take a break from talking with the teams and grab a beverage or snack in the lounge at any time.

GRADING

We seek to achieve consistency in grading between the teams. With that in mind, the senior design faculty has developed the scoring rubric. Each row includes prompting descriptions that are intended to guide the evaluation process. Each description has an associated point value with it.

To completely grade a team, please select a single number from each row of the grading matrix. Sum the numbers (one from each row) and enter the total team score at the bottom of the ballot. Please return the form to the registration table when it is complete.

Fall 2014 Design Projects

Each year senior students in the civil, electrical, environmental, and mechanical engineering programs in the College of Engineering and Computational Sciences take a two-semester course sequence in engineering design targeted at enhancing their problem-solving skills. Corporations, government agencies and other professional organizations, as well as individual clients, provide projects for the student teams of five to eight students to work on. Students spend the academic year developing solutions for the projects to which they have been assigned, using tools they have learned throughout their careers at Mines.

This semester, we are proud to present the work of our 9 design teams. Their collaborative design work culminates in today’s Senior Design Trade Fair. A list of the teams is provided below. In addition, each team has provided a one page synopsis of their design challenge which is included in the following pages.

TABLE OF PROJECTS

Team Number	Team Name	Project
S14-01	CSM FlightLab	Trampoline Time of Flight-USOC/NI
S14-02	CSM Outreach Engineering	Sustainable Modular Housing
S14-03	JB Engineering	Jalapa Nicaragua School
S14-04	Auto Leveling MakerBots (AutoBots)	3D Printer Build Platform Auto Leveling System
S14-05	SolTrak	Solar Pump Tracking Mechanism
S14-06	Aero Peak	Aero Peak – Spoiler Redesign
S14-07	Team 5DOF	6 DOF Test Frame
S14-08	RedLine Performance Engineering	FSAE Active Aerodynamic System
S14-09	Rapid Drilling Data	High Data Rate Pulser

Trampoline Time of Flight-USOC/NI

01

Client(s): United States Olympic Committee, Dr. Zok
Faculty Advisor: Dr. Bach
Technical/Social Context Consultants: Sam Strickling
Team Name: CSM FlightLab
Team Members: Mike Blaise, Adam Casanova, Andrew Eberle, Austin Elliott, Kelli Kravetz, Perry Taga

---

Time of Flight (ToF) was added as a scoring metric to the sport of Olympic Trampoline in 2010. The time that the athlete is not in contact with the trampoline surface during the scored skills, is measured, summed and calculated as an addition to the athletes' overall score. This is an easily measured and tracked aspect of an athlete's development. To this end, the United States Olympic Committee (USOC) has asked us to produce an inexpensive alternative to the commercially available ToF devices. We were asked specifically; "Using NI hardware and software students will create a way to collect the time of flight of trampoline athletes for a series of jumps and display the data" (original abstract).

CSM FlightLab will provide the USOC with a functioning ToF system that uses the NI myRIO for data collection and Idec type SA1E-TN2-2M through-beam photoelectric sensors for timing. We will provide a user interface that will communicate with NI LabVIEW to display this information. The program will also store athlete information for future review and comparison. Beyond the basic ToF metric, our system will have the initial design and prototype for the addition of live video feed and automatic sensing of foot position on the trampoline.

The development of this product has included prototyping and verification using one of the existing commercial ToF devices that was provided to us by Dr. Zok. Additionally we followed criteria established by the Federation International de Gymnastic for timing devices in order to produce a product that could be used for training and competition.

Sustainable Modular Housing

02

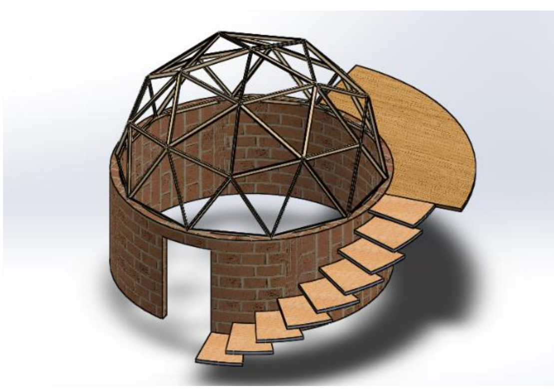
Client(s): Wes Umemura
Faculty Advisor: Judith Wang
Technical/Social Context Consultants: Susan Reynolds, Jessica Rolston
Team Name: CSM Outreach Engineering
Team Members: Victoria Billings, Ian Bloomfield, Taylor Duran, Aaron Heldmyer, Jeryl Sandoval, Jace Warren, Preston Wierzba

---

The Pine Ridge Reservation, located in southwest South Dakota, is a Native American community living in conditions of extreme poverty: alcoholism, suicide, inadequate heat and shelter, and unavailability of public services are only some of the issues many on the reservation must endure on a daily basis. Wes Umemura and the Lakota Outreach organization has approached CSM Outreach Engineering with the task of designing a sustainable modular house that is not only cost-effective and quick to construct, but will last for many years to come. It is the intent to construct approximately 4,000 of these homes to combat the overwhelming homelessness problems on the reservation.

CSM Outreach Engineering has designed a geodesic dome house, built partially underground to maximize heat efficiency and avoid frozen pipes during the frigid winter months. Stairs on the outside wrap around the building and lead to a sub-grade front door. The footprint of the dome house itself is about 314 sf, with a diameter of 20 ft, and features an open floor plan with a second floor loft accessible by ladder. The triangular windows at loft level provide a means of egress in the event of an emergency, as well as abundant natural light, and are positioned to avoid direct sunlight in the summer and maximize passive heating in the winter. Exterior to the house is a small patio at ground level, and an overhang above the stairwell provides shade and a barrier against snow buildup during winter. A French drainage system is included for rainwater mitigation and collection. Subsequent teams are expected to continue refining the design and analyzing subsystems.

Initial Conceptual Design.



Jalapa Nicaragua School

03

Client(s): Edge of Seven
Faculty Advisor: Judith Wang
Technical/Social Context Consultants: Joe Crocker, Juan Lucena
Team Name: JB Engineering
Team Members: Ali Khavari, Brian Klatt, Jasmine Solis, Matt Craighead, Steven Johnson

---

JB Engineering has developed a lateral force resisting system (LFRS) for a school in the first phase of a planned campus in Jalapa, Nicaragua. Our client, Edge of Seven, is developing this project. The developed LFRS is a reinforced concrete frame with masonry infill (RC). After research into multiple materials and building techniques including Compressed Earth Blocks (CEB), Wattle and Daub and Concrete Masonry Units, JB Engineering and Edge of Seven chose to proceed with the RC design. This design uses local bricks and concrete, with the intent of replacing local bricks with CEB in future phases. We performed concrete compression testing in order to evaluate the compressive strength of locally prepared concrete. In addition, we tested a locally available brick to determine its compressive strength. To ensure safety in both earthquakes and hurricanes, the team utilized a combination of the Nicaraguan National Building Code and ASCE 07 design specifications when designing the system. We performed a cost analysis of the RC construction method using local pricing and material availability. Furthermore the team took into account the needs of the students and instructors, from interviews with a Nicaraguan teacher and several volunteers. Ventilation, lighting and sound considerations were included in the design. The result is an efficiently designed school that suits the needs of our client and the local community.

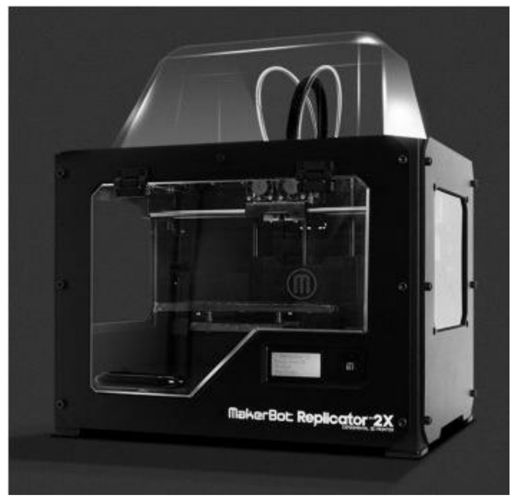
3D Printer Build Platform Auto Leveling System

04

Client(s): Prof. Jered Dean
Faculty Advisor: Dr. Judith Wang
Technical/Social Context Consultants: Dr. Jenifer Blacklock
Team Name: Auto Leveling MakerBots (AutoBots)
Team Members: Arveen Amiri, Dorian Illing, Adriana Johnson, Keeranat Kolatat, Jennifer McClellan

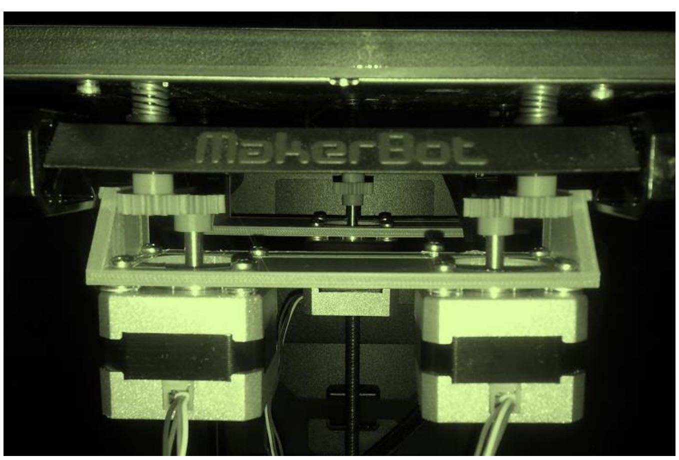
---

The Colorado School of Mines (CSM) acquired six MakerBot Replicator 2X 3D printers for use by the school and students. Using ABS plastic to print 3D objects layer by layer, the printers face several technical obstacles in achieving quality prints. The first step in printing is to level the build platform, the surface on which the print heads deposit plastic layers. The recommended leveling procedure involves iterative adjustments by hand to obtain a uniform space between the print head and the build plate in several locations using a piece of paper as a guide.



MakerBot Replicator 2X 3D Printer

The goal of this project was to create a low-cost, automated build plate leveling system that would be easy to install and maintain and simple to operate. This solution would ensure repeated successful builds without reducing the maximum printing size or requiring major modifications to the machine.



Stepper motors and gears installed on build platform

The final design solution involves a load cell mounted to the print head block that determines build platform position in multiple locations. Stepper motors are then engaged to position the build platform within the desired specifications using an Arduino Uno. Extensive testing and tolerance analysis revealed a target bed angle limit that would ensure quality prints. A complete drawing package of the final solution, verification test results, and an operation manual are some of the deliverables found in the final report.

Solar Pump Tracking Mechanism

05

Client(s): iDE – Ryan Weber
Faculty Advisor: Judith Wang
Technical/Social Context Consultants: Jered Dean, David Frossard
Team Name: SolTrak
Team Members: Miranda Barron, Lincoln Engelhard, Oluwaseun Ogunmodede, Brenda Ramirez, Eric Rosing, Kevin Wagner

---

SolTrak was tasked by iDE to design a sun-tracking mechanism to be used in conjunction with a steam-powered pump for small-scale irrigation in developing countries. The low cost design must efficiently track the sun and mechanically move the pump's solar dish. The main challenges faced during the design process were making the tracker economically feasible and using only materials that could be found locally in developing countries. To satisfy the client's requirements, three prototypes were created: electrical, steam-powered, and passive. Each of the designs incorporates the effects of wind force, sun angles, and environmental conditions. The electrical design (left) uses photoresistors, solar panels, and a gearbox motor to move the dish. Photoresistors, placed in strategic locations, detect when the dish is no longer directed at the sun and allow the solar panels to power the motor and rotate the dish. The steam-powered design (middle) utilizes the concentrated sunlight to create steam in a second boiler. As the sun rotates, the concentrated light shifts from the main boiler to the second boiler, creating steam pressure which powers a piston that moves the dish. The passive design (right) involves a counterweight on one side of the dish and an enclosed bucket system on the opposite side. The bucket contains a small drainage hole allowing water to drain at a predetermined rate during the day, thus causing the dish to rotate due to the counterweight.

06

Aero Peak – Spoiler Redesign

Client(s): Dan Novembre
Faculty Advisor: Buddy Haun
Technical/Social Context Consultants: Derrick Rodrigues
Team Name: Aero Peak
Team Members: Garret Bowling, Jordan Dicksteen, Mark Hendrix, Ian McFadden, Chris Smiley, Paul Soldo

---

We are tasked with redesigning the front and rear spoiler for Dan Novembre's "Pike's Peak Hill Climb Race" car.

We used several tools available to us through the school to design test and improve on the current setup. We are using a material called Polystrand a material made of fiber glass mixed with thermoplastic, it behaves similarly to carbon fiber but at a reduced cost. We are designing within the limitations of the race rules and keeping safety a paramount concern.

6 DOF Test Frame

07

Client(s): Dr. Cameron Turner
Faculty Advisor: Buddy Haun
Technical Context Consultants: Dr. Ozkan Celik, John Steuben
Team Name: Team 5DOF
Team Members: Brandon Hentges, Andrew Hulse, Jen Allen, Taylor Parsons, Sam Tillery

---

The purpose of the project was to develop a 6 degree of freedom test frame to determine the elastic properties of 3D printed plastic. The test frame should be able to induce any combination of forces and moments on the specimens and be able to break the specimens in all or most loading scenarios. The forces experienced by the specimen should be read by a force transducer or combination of force transducers and the full-field strain of the specimen should be captured. The types of specimens that will be tested in the test frame can be seen in Figure 1 below.

The test frame designed to satisfy these criteria may be seen in Figure 2 below. It is a hexapod design which will be able to produce any combination of force or moment on the specimens through pitch, yaw, and roll motions of the top plate. The forces and moments experienced by the specimen will be read by a single six-axis force/torque transducer with the option of a second transducer. The full-field strain will be captured and measured using digital image correlation.

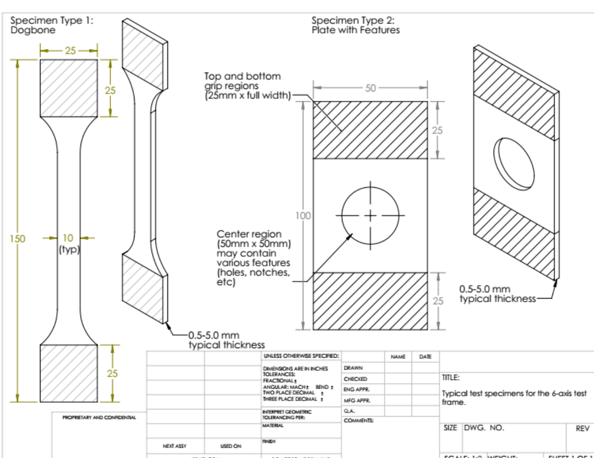


Figure 1: 3D Printed Specimens

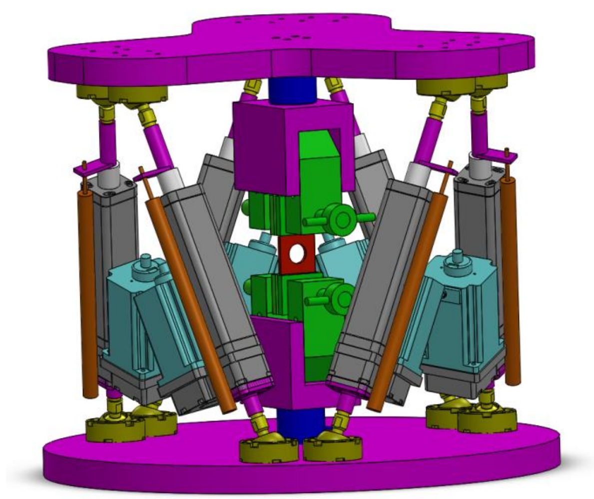


Figure 2: Final Test Frame Design

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

FSAE Active Aerodynamic System

08

Client(s):	Dr. Gregory Bogin
Faculty Advisor:	Buddy Haun
Technical/Social Context Consultants:	Dr. Jeff Schowalter
Team Name:	RedLine Performance Engineering
Team Members:	Peter Hansen, Arlen Kostival, Lizzie Miskovetz, Dan Romano, Tyler Stroh, and Sara Winberry

Formula SAE is a division of the Society of Automotive Engineers tasked with the annual design and build of a single person, formula-style race car, to be entered in an international competition. RedLine Performance Engineering was tasked with implementing an active aerodynamic system on the rear wing to improve the performance of FSAE's 2015 car. The team's overall goal is to vary drag on the rear wing at critical points around the race track, resulting in faster acceleration and lap times, or to assist in braking before turns. In order to comply with project expectations, the team was responsible for delivering a computational fluid dynamics (CFD) analysis, full SolidWorks CAD models, an engineering drawing package with a bill of materials, and a working prototype if sufficient budget was available.

2014 CSM FSAE Car with Aerodynamic Package

The team has retrofitted the rear aerodynamic wing assembly from the 2014 FSAE car to automatically open and close as the car moves around the race track. A control system with data acquisition has been implemented to monitor vehicle speed and direction, and will analyze the data to quickly open or close the top two wing elements for faster accelerations and cornering times. The system integrates this control system with a pneumatic air tank and linear actuator to move the desired elements of the wing. Prior to final implementation, the team analyzed the design's viability using CFD analysis, analytical calculations, and real-time testing. The team will hand off the finished product to the FSAE team for track testing next semester. The team is excited to implement the design on the 2015 car in an effort to make the vehicle more competitive in dynamic racing events.

High Data Rate Pulser

09

Client(s):	Darcy Wiebe, Rene Ray
Faculty Advisor:	Buddy Haun
Technical/Social Context Consultants:	Greg Jackson
Team Name:	Rapid Drilling Data
Team Members:	Samuel Grossman, Jeremy Hansmann, Jacob Jahner, Quade Lusk, Ryan Marsini, Colton Sauer

Team Rapid Drilling Data has been contracted by Focus Tools, LLC, to design a more effective Measurement While Drilling (MWD) telemetry system. The client's system uses regulated pressure pulses to transmit data through drilling mud and is able to pass data from up to 30,000 feet downhole. The client requires a pulser that will transmit data from downhole wells at a rate eight times greater than their current design of ½ bit per second.

Our approach was to conceptualize multiple designs and use a decision matrix to choose the best type of rotating pulser. We modeled the part in SolidWorks and printed each variation with a 3-D printer. Once we had a physical prototype, testing commenced. Physical testing consisted of placing our differing configurations in both a wind tunnel and a water flow loop. We also utilized finite element analysis studies in SolidWorks to examine for stress concentrations due to the high static pressures. From these analyses, we selected a design that will wear on non-critical features and will meet the initial goals. Theoretical wave attenuation calculations were also completed for this pulser.

The selected design will rotate downhole to create pressure pulses that can be read by a transducer at the surface. This pulse can be decoded at the surface to determine downhole drilling conditions and drill bit orientation. With this design, the information transfer rate should occur at a much faster rate. The material chosen for the final assembly is polycrystalline diamond due to its strength and wear characteristics. Drawings and prototypes of this design have been produced and tested, meeting the initial project goals.

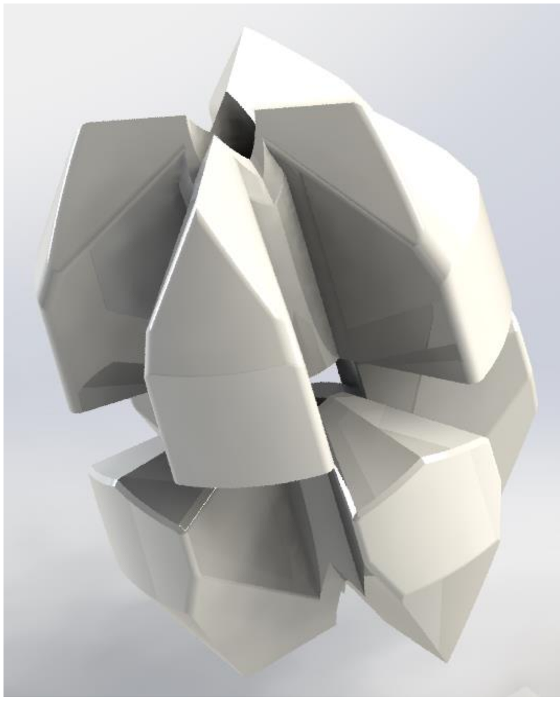


Figure 3: Data Pulser, Stator (top) and Rotor (bottom)

Individual Broader Impacts Essay

This semester all Senior Design students were assigned to write and submit an individual, 1500 word essay about how their engineering choices impact the social, environmental, and/or economic lives of communities and individuals. The top 10 essays from this group of 55 senior engineering students were chosen by the course faculty and are included in the Program in alphabetical order.

The top essays have been judged by a panel of volunteer judges and winners of the best essay contest will be announced along with the Trade Fair results.

This year's judges were:

Brenda Chergo
Tony Petrella
John Steele

We thank you very much for your time and effort involved in choosing the top essays!

The topic for this semester's essay is:

How do you manage your responsibility as an engineer in light of the unavoidable trade-offs between social, environmental, and/or economic considerations? For example, as a junior engineer in the energy industry how would you grapple with the complexity of working on a fracking project? Present a discussion, using an example, of engineers balancing these considerations that is either related to your project or your field of engineering.

COLORADOSCHOOLOFMINES
EARTH • ENERGY • ENVIRONMENT

ENGINEERING WITH CONSEQUENCES

by Glenn Duran

Growing up with a wise and worldly father, he always let my sister and I make our own decisions. When we would ask him for advice in our lives, his response was generally something like: "Do what makes you happy….Just be ready to face the consequences of your actions." This could have been dangerous encouragement for us as children, but instead has served as wise advice for us as young adults seeking out careers. With this embedded in my way of thought since childhood, I have made decisions very cautiously because I consider the repercussions of my actions. In particular, I have always been mindful of what I do and how it affects the lives of other people and society. As an engineer, the consequences of my actions tend to be more obvious than in many occupations. There are multiples scenarios where a bad engineering decision could have horrible implications for human lives and could cost millions to redress for the company at fault. For instance, a badly designed bridge, a faulty turbine, or an electronic brake failure that leads to mass recall are all engineering nightmares hopefully avoided by myself and future engineers. However, the first rule of the code of ethics for engineering states: "Engineers in the fulfillment of their duties shall hold paramount the safety, health, and welfare of the public." [1] This statement, along with knowing that we as engineers go through a rigorous education, leads me to believe having a catastrophic design flaw due to a neglected technical detail is fairly uncommon in most engineering practice. So not including the consequences of negligent engineers or individuals, it can be argued that the largest impact an engineer will have on society and globally is the impact the company makes as a whole.

When thinking about what career path to take, most engineering students are primarily impacted by economic influence and lean towards industries that have the deepest pockets. Besides careers in the petroleum industry, these are generally department of defense and aerospace related industries. Aerospace and defense industries provide a great service for society and globally their products and services are in high demand. A career in the aerospace and defense industry offers a highly competitive salary and numerous opportunities to work with cutting edge technology that requires a security clearance to even know about. Also, because the success of the industry depends on political dissonance and the policies that affect it, there is immense job security with growing political conflict around the world. On the other hand, there are many current political issues facing this and other industries. I were to find myself working for a company I disagreed with morally or ethically then it may be hard for me to be a faithful employee. This personal dilemma in itself would also conflict with the engineering code of ethics. Fortunately, I had the opportunity to work for a major department of defense contractor as an intern and was able to form my own opinion on the matter.

I applied to a large department of defense contractor in the aerospace industry my freshman year at Mines. Being a new student I didn't imagine I would actually get a job, but as I've been told many times before, "It's not what you know, it's who you know." Using this to my advantage I called my uncle who is a higher level executive with the company. Within a few weeks it was apparent he was able to pull some strings. I was contacted directly by my future boss and after only one quick phone interview I had been offered an internship. So, even though I got the job, it was disappointing to reveal that my new employer has people in positions of management practicing questionably unethical behavior. However, gross nepotism in the field of engineering and corporate society in general is not the ethical dilemma I would like to address.

During the new employee training for my internship, I was handed a Code of Ethics and Business Conduct handbook. On the there was a quote about the company values that read, "…we operate with integrity, excellence, accountability and respect in everything we do. Our values provide the foundation for our commitment to the highest level of ethical conduct, a commitment we take very seriously [2]." Specifically mentioned in the handbook are the values respect and integrity. Merriam-Webster defines respect as "… a feeling or understanding that someone or something is important, serious, etc., and should be treated in an appropriate way" and uses the phrasing "incorruptible" to define integrity [3]. In my mind, respect in this case refers to understanding the severe global implications of the work a United States defense contractor may have on society and treating it accordingly. Secondly, integrity refers how employees of the company should conduct themselves at all times. Since the internship opportunity, the media and news have brought to attention the work of my previous employer and some of the facts unearthed in the process made me uneasy because serious respect for human lives was neglected. Also, the company's integrity as a whole was questioned when evidence of bribery and an accounting scandal was brought to light. Taking bribes and mishandling accounts for government agencies is corrupt by definition and does not reflect the level of commitment to honesty and integrity that the company values so greatly. Though it may have been the actions of a few individuals who were most likely not engineers, the company's reputation suffered due to the consequences of the individual's actions.

This contractor designs and manufactures surveillance, intelligence, and reconnaissance equipment for airplanes and UAVs, also known as drones. The same company is also responsible for the millimeter wave body scanning machines used in airport TSA searches. With both of these being huge points of controversy in the news, it is tasking for me as an engineer to interpret the difficult dilemma of working for a company that is responsible for producing these technologies. For instance, a UAV, or drone, is a great engineering feat that saves and protects lives by taking soldiers out of the way of harm and by making it impossible for terrorists to hide. Additionally, the body scanning machines in use at the airports leave individuals with nothing to hide making it nearly impossible for someone to walk on an airplane with something dangerous or explosive. On the surface, both of these technologies increase the safety or security of citizens in the United States and reflect an understanding for the importance of human lives by trying to protect them and thus showing respect towards humanity and society as whole. Though with a deeper examination, it's evident that both UAVs and body scanners alike have been used to violate human rights and freedoms which display a huge lack of respect. Body scanners are often misused by TSA agents and may be considered a huge invasion of individual privacy. Also, drones have been used in covert bombing campaigns resulting in deaths and used to perform domestic surveillance on American citizens. After discovering this, I began to consider the severe moral, social, and global implications of the work I would be responsible for as an engineer working under a department of defense contractor like this. It is obvious that technologies like body scanners and unmanned drones are implemented to protect and save lives and that the service provided by this and similar companies is much needed given the world political situation. However, it is important to recognize the complex global and social implications of the legal decisions set forth to govern these technologies and the effects that they have on individual human lives.

A famous quote by Benjamin Franklin says, "Those who would give up essential liberty to purchase a little temporary safety deserve neither liberty nor safety."[4] I believe his comment is directly applicable to today's situation and that as engineers we need to make deliberate decisions that affect the public's health, safety, and freedom in a positive way for future generations. As an engineer, I will not have complete control on how technology I design will be used but it is crucial to be mindful of the larger effects my work may have. In this case, designing and implementing cutting edge technology for a department of defense contractor implies that it's possible the technology could be used to negatively affect the health and safety of human lives in the public. Also, this technology could be used to influence politics in an unfavorable manner. When dealing with controversial technology, the ethical responsibility as an engineer to honor the safety, health and welfare of the public may not encompass personal moral obligations. In difficult situations like this, I still find that my dad's wise yet simple advice to be the most helpful. After looking at the consequences of working for a major defense contractor, and the broader impacts the products themselves may have, it may be difficult to be happy knowing my actions could ultimately cost lives and impinge on basic freedoms.

References

[1] "Code of Ethics and Business Conduct." L-3 Code of Ethics & Business Conduct. N.p., n.d. Web. 24 Oct. 2014. http://www.l-3com.com/code-of-ethics-and-business-conduct
[2] "Code of Ethics." National Society of Professional Engineers. N.p., n.d. Web. 21 Oct. 2014. <http://www.nspe.org/resources/ethics/code-ethics>.
[3] Merriam-Webster. Merriam-Webster, n.d. Web. 23 Oct. 2014. <http://www.merriam-webster.com/>
[4] Benjamin Franklin. Historical Review of Pennsylvania, 1759

A DAY IN MANHATTAN

by Sam Grossman

As engineers, we voluntarily assume a responsibility for the health and welfare of the public. This is our first duty as professionals but also a task to which we are uniquely suited. Due to our training and experience with reason and its systematic implementation engineers approach problems from a different perspective than any other professional discipline. The Code of Ethics for Engineers, as curated by the National Society of Professional Engineers, elucidates this reasoning while providing a general framework from which to evaluate the multitude of issues faced by engineers in industry. We are not constrained by a singular devotion to our client, as in law, or a vow to do no harm like the Hippocratic Oath. Instead, we as engineers are tasked with maintaining the general safety of those around us. Our concerns and thoughts must be constantly turned the totality of our impact on the world. It is not enough to concern ourselves with the person we see, but the hundreds or thousands we don't.

Our profession is tasked with enabling some of the greatest achievements of humanity but also some of its greatest horrors. This opens a new avenue for ethical consideration, is it simply enough to act ethically in your own life while pursuing some ultimately immoral goal? Do we have an ethical obligation to simply do quality work and maintain ethical work standards, or does that responsibility extend to the ways in which our work may be used as well? Strict liability would tell us that we have a legal obligation for the consequences of intentional misuse but there is no simple framework to evaluate working on a project like the Manhattan Project. The Manhattan Project is a seminal case for engineering ethics and choosing between mutually exclusive goals. Imagine living in Los Alamos, American war dead increasing by the thousands every day and on the horizon is a glimmer of hope, hope for the end of all war. In a state of total war the calculus of people changes substantially making the decisions of the scientists and engineers working on the project difficult to evaluate from our comfortable and safe positions today.

The Manhattan Project and nuclear energy in general epitomize the tradeoff between social, environmental and economic considerations. No other tool in the history of the planet had and continues to have the potential to utterly reshape all three of these areas to such a great extent. In the beginning of the atomic age the proposed societal and economic benefits of nuclear energy seemed boundless. From your car, to the next generation of airplanes, to your own home reactor, nuclear energy was the panacea for all that ailed society. Within a short period of time we began to fully grasp the dangers of ionizing radiation. We also scaled our nuclear projects to a point of generating considerable amounts of long lived, toxic waste. In our hubris to utilize this vast and new source of energy we neglected to fully imagine the costs of our labors. Around this time the world saw for the first time large scale nuclear proliferation. Literally dozens of nations possessed or seriously pursued nuclear capabilities [1]. For all the economic and societal promise of cheap, plentiful energy we suddenly found ourselves with very real nuclear emergencies. Among these the partial meltdown of one of Three Mile Island's two reactors in 1979 showed the potential environmental dangers of nuclear science in sharp relief. The subsequent investigation revealed many oversights that would be considered flawed practice today. For example a valve position indicator was instead connected to the solenoid powering the valve and gave a false reading when there was a mechanical fault in the valve itself, although the solenoid functioned correctly at all times. This fault led in part to a release of unknown amounts of radioactivity into the environment and a subsequent cleanup effort totaling $1 billion [2].

In the role of devil's advocate let us imagine a world in which our engineers objected to creating the ultimate weapon of mass destruction for a multitude of moral and ethical reasons. On the other hand our enemies, in their lust for global domination, continued headlong and made a working bomb despite our refusal. Did the original ethical concerns of the engineers, justified as they were, result in a net protective effect on the public? In my opinion they did not, highlighting the intense complexity of issues faced by engineers. As a mechanical engineer my skills could be needed to help defend the country if we were to experience another protracted world war. Every piece of equipment in service by our military has been designed or tested by engineers. While designing body armor or a new personal cooling system for desert warfare are by no means unethical, someone has to design the guns and ammunition. Mikhail Kalashnikov, who gained fame as the designer of the AK-47 assault rifle, once said "I sleep well. It's the politicians who are to blame for failing to come to an agreement and resorting to violence."[3] While politicians could certainly do better Mr. Kalashnikov's head in the sand approach is by no means appropriate. Just as in the case of sudden acceleration in certain Toyota and Lexus models injuries caused by engineering decisions are the responsibility of the designing engineer. This duty is persistent and paramount.

As discussed above engineers are frequently thrust into uniquely challenging situations. As such each of us should be prepared to grapple with these issues at some point during their career. The sorts of ethical considerations most of us have or will encounter do not involve survival in the face of total annihilation or designing weapons of war. The issues encountered in practice tend to be more local, more personal. What do you say when you know or suspect an environmental report has been whitewashed to fast track a project? Perhaps the company that employs you is looking at bankruptcy and without this project you and twenty of your coworkers will lose your jobs. There is an obvious ethical responsibility to adequately and accurately evaluate any considerations, environmental or otherwise, that may be unique to a site. What, if any, responsibility do you have to the other employees? Everyone's circumstance is different and losing this job might push a coworker to the end of their rope. There are no perfect answers to these questions. Instead we treat each situation individually, relying on our own internal ethical compass and our professional code/s of ethics.

Mechanical and infrastructure engineering interact with the general public intimately every day. Choices that we make during the design phase regarding parameters like safety factor or even geometry can drastically affect individual lives. In the case of ET plus guard rails a small design change was implemented by the company in breach of contractual obligations. By my previously established standards this decision is already clearly unethical, however the series of bad decisions continues. The company reduced the size of a steel channel used in a barrier end device meant to divert incoming cars. It is reasonable to assume that this change was made in an attempt to save money as they were in breach of contract as soon as the company implemented this design change. This new modified design has since been involved in a number of fatal accidents and based on available testing the new design experiences performance issues that the older, presumably more costly, design did not [4].

As professionals, engineers benefit from a history of trust and general ethical behavior with concern to the general public. It is our duty, both as individual engineers and as engineering professionals as a group, to maintain the public's confidence. A rigorous investigation of engineering ethics and ethical considerations is the only way to preserve this facet of our profession. There is a precedent in the scientific and engineering community of investigating public or catastrophic failures as a way to improve future designs and the design process. In the earlier example of problems in the design of the Three Mile Island control room, we did not simply notice these issues and figure we would do better the next time. The issues identified in the subsequent investigations were instead incorporated into new and operating plants resulting in a much cleaner and easier to use set of controls for most nuclear facilities. As we know, there has not been a significant nuclear event in this country since 1979. We as engineers are tasked with protecting the weakest and most vulnerable in society, designing hospitals and schools, the pumps that bring us drinking water and the systems that make the stuff in the toilet go away when you flush it. We are allowed to affect almost every portion of life without reservation. This represents a sacred trust between engineers and the general public, a trust we are obligated to defend relentlessly.

References

[1] The Nuclear Energy Futures Project, Centre for International Governance Innovation, Waterloo and the Canadian Centre for Treaty Compliance, Carleton University, Ottawa, Canada. GIVING UP THE BOMB: MOTIVATIONS AND INCENTIVES. Research Paper. The International Commission on Nuclear Non-proliferation and Disarmament, n.d. Web.
[2] Archived. "14-Year Cleanup at Three Mile Island Concludes." The New York Times. The New York Times, 15 Aug. 1998. Web. 23 Oct. 2014.
[3] Heintz, Jim. "AK-47 Inventor Mikhail Kalashnikov Dead at 94." Military Times. N.p., 23 Dec. 2013. Web. 23 Oct. 2014.
[4] Ivory, Danielle, and Aaron M. Kessler. "Highway Guardrail May Be Deadly, States Say." The New York Times. The New York Times, 12 Oct. 2014. Web. 23 Oct. 2014.

THE MODERN RENAISSANCE MEN AND WOMEN

by Aaron Heldmyer

It is evident that now more than ever, there is a concentration of skill the engineer is expected to embody above all other professions. This is the burden of flexibility: engineers remain expected to hold the standard applied mathematical and scientific background, true, but this is a mere fraction of what is asked of us today. We must have the articulation and scholarly inclinations of a writer. We must find within ourselves the creative sensibilities of an architect or painter. To communicate with a diversity of potentially underprivileged clients requires the doctor's bedside manner. In winning bids or promoting extraordinary new ideas, the force of will and cunning of a politician is necessary. The good business sense of executives and entrepreneurs must also be readily available, sometimes at a mere moment's notice. And to push the limits of what human society is capable of, as we do every day, engineers must exemplify the audacity and imagination of the inventor.

To the budding engineering student, this notion seems daunting and, at times, even paralyzing. Here looming before us is a seemingly unanswerable challenge to incorporate social, environmental, and economic considerations of considerable weight into every decision we make as a professional. Every misstep might have disastrous consequences. Working on a humanitarian engineering project for example, designing housing for a disparaged Native American tribe like the Lakota Sioux, to whom life has offered very little, is a high-stakes gamble with extremely limited resources and time. But seeing life from another's eyes, to know the challenges and hardships that a completely different walk of life faces, is to also see a solution. That is, to be an engineer, ready to face a multitude of varied challenges, is to live life fully and completely. Practice music, read literature, play sports, experience foreign cultures and lands, create astounding and entirely useless gadgets and gizmos. The brain is a powerful thing: the answers to high-complexity engineering problems very often stems from seemingly unrelated knowledge. Oftentimes it is our creative passions, and not our technical experience, that provide the most innovative solutions to the multifaceted and unfamiliar problems we may encounter.

Every person who has ever written a resume is familiar with the concept of transferable skills. Because it is unlikely to have exactly the right education and experience for a desired job, we explain to prospective employers that the importance of experience lies beyond the technical, into what could perhaps be considered a more metaphysical domain: that of the mind. As the privileged, higher-functioning organisms that we are, we innately possess the unique ability to apply knowledge gained from one situation to another. In a process known colloquially as “creative problem-solving”, we approach tasks with which we are unfamiliar in a cyclical process. We explore the nature of the problem, research related information, generate ideas through brainstorming and collaboration, and find a solution for which to seek acceptance from all parties involved [1]. This process is repeated again and again, essentially refining the rough idea until it is not only feasible, but the most feasible solution of the time. While brainstorming design solutions for the Lakota Sioux housing project, it became necessary to conduct a public forum to communicate the idea our team had previously devised. Through this established contact, the solution we proposed underwent further refinement as new information was introduced: the needs and concerns of the community. This became yet another metamorphosis of our intended design created through this cyclical creative process. And, as evidenced, to complete even one cycle requires at its very minimum a repertoire of communication skills, creativity, and technical knowledge.

Travel is an inescapable reality for many engineers. Projects or clients may be located a few blocks away, or in a completely different country. Engineers might also attend conferences or external meetings on a regular basis, though there are few professionals who jump at the opportunity to leave loved ones behind for extended periods of time for business-related endeavors. However, there is an undeniable advantage that frequent travelers enjoy over their more stationary counterparts. Much like many of the famous artists and writers over the past several centuries like Pablo Picasso, Rudyard Kipling, and Ernest Hemingway, travelers have been found to be much more creative. In a study published in the Journal of Personality and Social Psychology, researchers found that 60% of those students studied who were foreign or had lived abroad, compared to 42% who were American and had not lived abroad, were able to solve a problem in which they were given a candle, some matches, and a box of drawing pins and asked to affix the candle to the wall so that no wax would drip to the floor (the solution was to use the box as a candleholder). Additionally, negotiation skills were tested in a follow-up study with similar results. Students were paired off, with one being the seller of a petrol station who would then need a job, and the other a buyer who would need to hire staff to run the business. The experiment was set up so that reaching an impasse was likely, as the buyer was told he could not afford the seller’s minimum asking price. Despite this, in cases where both students had lived abroad, 70% reached an agreement where the seller would be offered a management position in exchange for a lower asking price [2]. These findings show a definitive link between living or working away from home and a capacity for problem-solving that was previously understood only anecdotally. Thus, the benefits enjoyed by an engineer who travels becomes readily apparent. Our senior design team was fortunate in that we were afforded multiple opportunities to visit the location of our project. Of course, we conducted soil tests and took careful documentation of the topography and available infrastructure, but we also visited a cultural heritage museum to better understand the Native American community. We walked through cemeteries, visited a local high school, navigated the site of the Battle of the Wounded Knee, and even toured an award-winning Catholic church that blended aspects of their culture with the Catholic faith. Some of the most important design concepts arose from these "extraneous" ventures, including the decision to make the housing model round, out of respect for their cultural view that the circle is a profound shape that brings people together as equals.

Travel is one example with implications on the engineer's ability to succeed, but what of poetry, or fictional writing? Surely these esoteric pursuits are hardly worth the time of a studious young engineer? Not according to Alan Lightman, an accomplished physicist and professor at MIT, as well as celebrated writer and author of the novel Einstein's Dreams. An international bestseller, this collection of fictional vignettes imaginatively details new and otherworldly concepts of time that have inspired countless playwrights, dancers, and musicians the world over, and has helped illustrate the importance of the connection between science and art [3]. Moreover, the realms of science fiction and fact share a long mutual history, as evidenced through famous thinkers like Isaac Asimov, a biochemistry professor at Boston University famous for his science-fiction pieces [4], and our own beloved Neil DeGrasse Tyson, exploring the universe from within the "spaceship of the imagination" in the popular television program, Cosmos: A Spacetime Odyssey [5].

Of course, creativity and imagination have their limitations without the required education to provide a suitable foundation. We apprehensive young engineers, anxious about our abilities to manage the social aspects, environmental aspects, economic aspects, and any other aspects of our work, must invariably grasp the basic technical skills the situation demands. This is unavoidable for success. To design a dome house requires an exceptional knowledge of foundations, structural capacity, thermal demands of materials, load-bearing capabilities, and energy acquisition and use. To budget a house requires knowledge of standard price of materials, cost of labor, maintenance regularity, and long-term economic outlook. And to understand the social situation of a community requires understanding of rates of homelessness, suicide, and alcoholism, as well as social stratification, laws, and culture. However, the importance of exploring the world around us, whether through prose, tennis, sculpting, travel, or learning a new language, cannot be understated with regards to applicability in engineering problem-solving. When a student dedicates herself to a passion, she is increasing her knowledge capital – that is, adding to her world understanding that not only yields self-assurance, but also a perspective that is uniquely her own: a perspective fundamental in achieving success in the face of unavoidable compromise.

Truthfully, there are those among us that prove invaluable in solving complex engineering problems using knowledge and technical capability alone. They can be helpful in a team of engineers for this computational skill and research ability, without necessarily providing much insofar as creativity is concerned. They can work all day without great need for pause, and have unwavering dedication to their work, and, at the end of the day, we shut them off. They are called computers.

References

[1] What is Creative Problem Solving? [Online]. Available: http://www.creativeeducationfoundation.org/our-process/what-is-cps
[2] (2009, May 14). Expats at Work [Online]. Available: http://www.economist.com/node/13643981
[3] A. Lightman, Einstein's Dreams. New York, NY: Pantheon Books, 1993
[4] Isaac Asimov Biography [Online]. Available: http://www.biography.com/people/isaac-asimov-9190737
[5] B. Brugan, B. Pope, A. Druyan, Cosmos: A Spacetime Odyssey.

THE WALL AROUND INNOVATION IN THE MEDICAL DEVICE MARKET

by Brandon Hentges

Many engineers are concerned with being on the cutting edge of technology and innovating new products and processes. In many cases, this is why an engineer will get into the medical device field. With so many engineers being recruited into the medical field for both research and development, it is important to address how a firm should behave economically to foster innovation. Companies within the medical devices industry make up a significant portion of the United States economy. The medical device industry is currently worth $118 billion and expected to continue to grow [1].

When creating new technology it is important to consider the impacts it will have once it hits the market. Companies must adhere to policies set by regulatory agencies such as the FDA. Although the company is in the research and development market, its goal is to maximize profit, just like any other firm. It is the engineer's responsibility to ensure that the product is completely safe and has gone through the correct testing and clinical trials prior to its release in the market.

This paper will analyze companies' innovation strategy within the medical device industry with attention to the economic considerations at the firm level. Barriers to entry and limiting factors for small businesses will be discussed in depth. In addition, this essay will consider the hurdle of regulatory agencies, such as the FDA, that the firm must overcome to get a new product to the market.

Innovation Strategies for Medical Device Industry

Although all companies strive to maximize profit, there are many ways that they can do this without endangering the safety, health or welfare of the public. Many companies doing research in the medical device area are considered to use an incremental innovation strategy. An incremental innovation is an innovation that does not completely change the technology; it makes it more efficient, or reliable in the medical device industry. Examples of these types of technologies could be a longer lasting pacemaker, or a higher sound quality hearing aid. Usually many companies are in the market for these devices and they tend to get into races to develop the technology faster than their competitor. This can cause companies to start to get into patent races which secure the profits of their innovation for an extended amount of time. Patent Races are inefficient because only the first company to get a patent earns the profits. The other companies' capital spent on research is essentially a dead weight loss that burdens the producer.

The effects of patent races can be intensified when it comes to drastic innovation. A drastic innovation "introduces a completely new type of production process with a wide range of applications" or "gives rise to a whole new genre of innovative products [2]." In the case of a drastic innovation, the company will employ the use of many patents to fully protect their product. The company may also use patent thickets to further protect the firm down the road. A patent thicket is a set of patents on individual design components of the innovation. Design patents usually last for many years which allow firms to protect their assets while finishing a design or conducting medical trials.

Although patents can aid a firm in protecting their intellectual property and securing future profits, patent strategies can have a negative effect on the medical device industry as well. One adverse effect is the high barriers to entry that there are for new companies entering the market. Patent thickets create high barriers to entry through the use of licensing. A new company entering the market will have to license individual components from different companies in order to create their new technology. Many times new firms do not have the capital for many licenses to cover the fees imposed by different incumbent producers.

Patent thickets and high barriers to entry create a fundamental problem within the medical device market. Many large firms rely on incremental innovation to gain new patents and increase their profits. By doing so, they hinder the innovative process that many small firms rely on. Although companies patent strategies allow them to secure future profits, some of these strategies harm innovation within the industry. The small innovative firms have high barriers to entry and they are the firms that are usually the most innovative.

Regulatory Agencies Effects on Innovation

In the medical device market, not only does the firm have to overcome the process of proving their technology worthy of a patent, they have to make sure the product is in compliance with regulations set forth by the FDA. This responsibility falls mainly on the shoulders of the engineer and the engineer should follow the code of ethics when innovating new products.

Many small firms who are doing research and development to create drastic innovations must also consider the implications of clearing their new device with the FDA. The FDA categorizes these new technologies into three classes. The first classes include common lab equipment such as thermometers. This class is said to have the least impact on the human body. The third class however is the most important to firms developing drastic innovations in the medical device market. The third class is described as a device “for a use in supporting or sustaining life [3].” These devices have to get pre-market approval by the FDA which involves a long process of approvals and clinical trials. The product will usually be patented with a proof of concept first to establish that the device works properly. The clinical trials stage will also further prove that the product is safe to be inside or in contact with the human body.

After the company has patented their new invention, they will need to use some of the time that the company gained by the patent to get FDA approval rather than maximize their profits. The FDA approval process can take years which creates a big problem for companies. Not only does the FDA approval process cut firms profits, it affects the innovation system for the entire market. Because the FDA approval process, companies will need to employ other strategies to protect their invention and extend their patent life. This once again fosters the use of patent thickets which decrease the efficiency of the innovation process for the entire market as discussed earlier.

Regulatory agencies pose a huge barrier to entry with new firms trying to gain enough capital to perform research and development of these new and life changing devices. With the vast amount of drastic innovation that small companies offer, the FDA can create problems when these small companies try to get investors. Many venture capitalists will want not only patents but also the clinical trial proof that the product is FDA approved. This makes the capital accumulation process extremely hard for small companies and leads to a continued “hold up” problem for innovation.

<u>Economic Considerations of Smaller Firms / Conclusion</u>

The innovation market as a whole is subject to many inefficiencies. Patent strategies and FDA hold up are the two main inefficiencies within the innovation market for medical devices. A company participates in the innovation of new technology to gain market power. This is the simplest way to explain why a new firm would enter the market in the first place. However, once in the market, a company needs to have strategies in place to protect their market share. These companies will try to lengthen their patent life and secure their market share. This grasp for power is the driving force of the inefficiency.

The innovation industry within the medical device market can be seen as land surrounded by a wall with one large gate. This wall is made up of blocks that prevent smaller firms from entering the innovation market. When large companies lengthen their patent life through the use of incremental development, they hinder the innovative spirit that this country has been striving to foster for decades. These are the building blocks within the formidable wall. Through the use of patent thickets and intellectual property protection, large companies can make the wall taller and stronger.

The gate represents the FDA. Clinical trials and pre-market approval is another barrier that small companies entering the market will have to pass through. The golden ticket to the gate is the capital that the small companies have to acquire. The small companies have to sit outside of the gate for many years until they have enough capital to enter.

The strong wall has many benefits for the larger companies within its perimeter. It protects their intellectual property and allows them to maximize their profits. However, this is not necessarily the best outcome for the effectiveness and efficiency of innovation. For a smaller company to enter the market, they must pass through the gate. Even though drastic innovations can fundamentally change the way that patients view health care, it takes many years for these devices to hit the market. The long process is proof of how inefficient the market is. In conclusion, the innovative spirit is being crushed by large companies who seek to maximize profits through incremental development of pre-existing innovations and small companies creating the life changing innovations have many barriers to overcome before hitting the market.

References

[1] Espicom, The World Medical Market Book 2013
[2] Greenhalgh, Christine, and Mark Rogers. "The Nature and Importance of Innovation." Innovation, Intellectual Property, and Economic Growth. Princeton: Princeton UP, 2010. 8-9. Print.
[3] Lewin, Adam. “Medical Device Innovation in America: Tensions Between Food and Drug Law and Patent Law.” Harvard Journal of Law & Technology 26.1 (2012: 405-406. Web 22 Oct. 2014.

COLORADOSCHOOLOFMINES
EARTH • ENERGY • ENVIRONMENT

THE EFFECTS OF THE SPOKANE RIVER TOTAL MAXIMUM DAILY LOAD

by Brian Klatt

In modern society it is common for individuals to look to their leaders to solve the pressing issues of the time. They frequently involve broad, sweeping measures intended to address complex and multi-faceted problems. As the foremost technical minds, engineers are regularly required to spearhead these efforts. A prime example of these programs is present in northern Idaho. Beginning in 2009 the Spokane River Total Maximum Daily Load[1] (TMDL) was modified to include new Designated Beneficial Uses (DBUs), initiating several years of debate and reform in municipalities across the Inland Northwest. This revolving issue is an optimal reflection of an engineer's duty to balance the social, environmental and economic considerations of a client and community.

The historic causes for the tighter TMDL originate with the headwaters of the Spokane River. The Spokane River acts as drainage for Lake Coeur d' Alene in northern Idaho before crossing over into eastern Washington. Idaho, nicknamed the gem state, has a long history of mining operations dating back to 1884's Sunshine Mine. These mining operations have created a large environmental hazard which culminated in a the Bunker Hill superfund cleanup action in 1983 due to high levels mining waste including heavy metals and lead [1]. These industrial activities have led to a large amount of pollutants being released into the groundwater supply. The northern Idaho region also has a large agricultural base, producing wheat, oats, mint, rice and several other crops as well as livestock. To maintain the agricultural production a large amount of fertilizer and pesticides have been applied to the area providing an additional pollutant to the groundwater, particularly nitrogen and phosphorous [2].

In addition to the elevated levels of pollutants in the water, the presence of the local Native American Tribes have provided additional complications. The Spokane Tribe has a Congressional Treaty protecting their rights and way of life which, although necessary, creates a unique situation for the DBUs. As historic hunter and gatherers, large amount of their sustenance comes from fishing in the Spokane River which has placed an additional emphasis on the health and sustainability of the fish in the river [3].

[1] The TMDL and all subsequent requirements are regulations laid out by the Environmental Protection Agency (EPA) to meet guidelines laid out by the Clean Water Act (CWA)

The State of Washington's Department of Ecology (WDOE) put forth a new proposal for the TMDL under growing pressure from multiple environmental groups as well as the Spokane Tribe to bring the level of PCBs down and dissolved oxygen content up, largely because the levels in the Spokane River are notably worse than those of other rivers in the region [4]. Due to the comprehensive nature of the CWA, any upstream discharger must comply with downstream regulation, regardless of state lines [5]. One critical upstream municipality in Idaho discharging into the Spokane River is the City of Post Falls, a rural town of approximately 27,000 people. The intention of the new TMDL is to reduce these problems and provide environmental protection and security for future generations [6].

The underlying guarantee is that by tightening the TMDL the quality of life will improve for downstream occupants. More specifically, that the increase in dissolved oxygen content and reduction in PCBs will increase the size and number of the fish as well as increase the life expectancy of those who live downstream [7]. It should be noted, however, that the success of the TMDL restrictions will not be measured through the effects on the downstream occupants but simply whether or not the requirements are met, nor are there any intended follow-up procedures planned by the regulating bodies to ensure that the intended outcomes of the regulation are actually realized. In addition, the upstream municipality, namely the City of Post Falls, will be responsible for constructing facilities capable of meeting these standards which will cost the city between $700 million and $1 billion for the phosphorous portion of the requirements and $2 to $3 billion for the PCB requirements [8].

The assumptions made when planning this regulation are extensive, and listed below:

- The reduction of phosphorous will improve the dissolved oxygen content
- The municipal treatment plants have a measurable and sizable impact on phosphorous and PCB levels in the Spokane River
- The reduction of chemicals being put into the river will have a noticeable and lasting impact on the health of the environment and community
- The water processing methods required to meet these levels are reliable and effective
- The treatment methods are affordable by the community being required to build them

These assumptions are widely disputed by the organizations within the State of Idaho, local municipalities and engineering consulting firms. It is claimed by local consulting firms that the reduction of phosphorous output from the treatment plants is so small that there is no measurable impact in the phosphorous levels of the river itself. Furthermore, a reduction of such a small number, from 1 part per million (ppm) to 0.036 ppm, would have such a negligible impact on the dissolved oxygen content that there would be no tangible benefit to the environment or society [9].

A similar claim can be made about PCB levels. Testing further north of the Spokane River, in water systems which ultimately feed into the river but are not effected by water treatment outflow have PCB levels nearly identical to those at the water treatment plant location, indicating that a reduction in PCB levels from the treatment plants will not reduce the overall PCB levels [10]. Statistically speaking an average person in the affected communities is more likely to die crossing the road than they are to die from the effects of PCBs at their current levels [11]. The probability of contracting cancer due to PCBs at the level they currently are in the Spokane River is approximately one in one million, resulting in a death from cancer among the Spokane Tribe about once every fifteen generations [12]. In fact, in several parts of the east coast there is a large push to bring PCB levels down to the same level as the ones that exist in the Spokane River currently, bringing into question why a stricter standard is being enforced in the Spokane River.

In addition to the arguable effects of the outcomes of the improved standards comes the difficulty in implementing them. There are very few treatment methods that can bring the phosphorous and PCB levels down to the TMDL's required levels and only a handful have been successfully implemented in the United States [13]. One of the few practical methods implemented is in Breckenridge, Colorado. But in order to implement these new processing techniques the municipalities will need a large amount of money, a total of between $1.7 and $3 billion [14]. In addition, these methods are still experimental and largely untested, leaving significant room for fluctuation. And should the municipality discharge water at an effluent higher than the allowable standard then the EPA can fine the municipalities up to $32,500 per day. The implementation of the standards alone will be a significant financial burden for the community. With only state loans and no apparent federal grants or aid coupled with the possibility that the process could fail and result in increased fines adds an additional fiscal problem.

With the evidence presented it would be easy to dismiss this regulation as excessive and inappropriately enforced [5].Yet upon a closer look this project is attempting to address a very real problem. The dissolved oxygen content in the river is significantly lower than others in the area (due to high phosphorous content) and the level of PCBs is significantly higher. This river does have a broad impact on several communities including the Spokane Tribe and this problem must be addressed [15]. And to an extent it is, the EPA and its engineers are handling it the only way they know how historically and the only way that is quantifiable: through regulating the effluent of water processing plants; however, this may not be the best approach to the problem which is giving rise to the debate.

Ultimately it is not possible for a single engineer to determine a clean solution to this issue, nor can it be approached from a single perspective. The conflict that is occurring between the regulating bodies and the municipalities is ultimately necessary and productive. If only the economic considerations were utilized in the design many social and environmental concerns would be neglected. Creating an environment which demands the best environmental and social considerations possible puts a strain on the engineers to make it economically feasible yet ultimately produces the best result. It forces innovation and creative thinking, new solutions which ultimately drives an improved understanding of how to meet the economic, social and environmental considerations of a society.

References

[1] K. Miller, "Kellogg Still Strives to Get the Lead Out," *Idaho Statesman,* p. 3, 2 July 2000.

[2] Environment News Service, "Washington Expands Water Quality Plan for Spokane River," 21 September 2009. [Online]. Available: http://www.ens-newswire.com/ens/sep2009/2009-09-21-091.asp. [Accessed 9 December 2009].

[3] Spokane Tribe of Indians, "Spokane River NPDES Permits," Wellpinit, 2011.

[4] C. J. Berger, R. L. Annear and S. A. Wells, "A Water Quality Model of the Spokane River-Long Lake System using CE-QUAL-W2," Water Environment Federation, 2002.

[5] Washington Department of Ecology, "Spokane River and Lake Spokane Dissolved Oxygen Total Maximum Daily Load," Spokane, 2010.

[6] D. Redline, "Comments on Draft Dissolved Oxygen Total Maximum Daily Load ("TMDL") report," City of Hayden, Hayden, Idaho, 2009.

[7] T. C. Werner, "Comments on Draft Dissolved Oxygen Total Maximum Daily Load ("TMDL") Report," City of Post Falls Public Works Department, Post Falls, Idaho, 2009.

[8] J-U-B Engineers, Inc., "Rathdrum Prairie Wastewater Master Plan," J-U-B Engineers, Inc., Kootenai County, Idaho, 2009.

[9] R. Annear, C. Berger, S. Wells and T. Cole, "Upper Spokane River Model: Boundary Conditions and Model Setup," Department of Civil Engineering, Portland State University, Portland, Oregon, 2001.

[10] Washington Department of Ecology, "Spokane River PCB Source Assessment," Spokane, 2011.

[11] P. A. Klatt and J.-U.-B. Engineers, "HARSB Wastewater Master Plan: An Update," J-U-B Engineers, Hayden, Idaho, 2009.

[12] Washington Department of Ecology, "Total Maximum Daily Load Study for PCBs in the Spokane River," Spokane, 2003.

[13] J. Neethling, C. Lancaster, G. Moller, A. B. Pincince, S. Smith and H. Zhang, "Tertiary Phosphorous Removal," Water Environment Research Foundation, 2008.

[14] United States Environmental Protection Agency, "Water & Wastewater Pricing," 26 May 2009. [Online]. Available: http://www.epa.gov/waterinfrastructure/pricing/index.htm. [Accessed 9 December 2009].

[15] The Lands Council of Washington, "Why Are We Concerned about Phosphorous," 2006. [Online]. Available: http://www.landscouncil.org/water/phosphorous.asp. [Accessed 9 December 2009].

[16] S. Wells, C. Berger and V. Wells, "Spokane River Modeling Report 2009," Portland State University, Portland, Oregon, 2009.

[17] S. Wells and C. Berger, "Spokane River in Idaho and Washington TMDL Water Quality and Hydrodynamic Modeling Quality Assurance," Portland State University, Portland, Oregon, 2009.

[18] C. Tortajada, "Singapore: An Exemplary Case for Urban Water Management," Third World Centre for Water Management, Atizapán, Mexico, 2006.

[19] M. Sullivan, "Australia Turns to Desalination Amid Water Shortage," 18 June 2007. [Online]. Available: http://www.npr.org/templates/story/story.php?storyId=11134967. [Accessed 9 December 2009].

[20] B. Pearce, "Water Reuse in San Diego," City of San Diego Water Department, Liberty Lake, Washington, 2009.

[21] K. Murphy, "The dirty truth: They're smuggling soap in Spokane," *Los Angeles Times*, pp. 1-3, 6 April 2009.

[22] D. Moore and J. Ross, "Spokane River and Lake Spokane Dissolved Oxygen Total Maximum Daily Load," State of Washington Department of Ecology, Spokane, Washington, 2009.

[23] A. Menniti, B. Sabherwal, M. C. Portillo, H. Wilner and P. J. Schuler, "Membranes 101: Fundamentals of Membrane Bioreactors and tertiary Membrane Filtration," Water Environment Federation, New Orleans, Louisiana, 2009.

[24] H. A. Majid, "Singapore News: Singapore Lends Expertise in Wastewater Management to Queensland," 11 April 2007. [Online]. Available: http://www.channelnewsasia.com/stories/singaporelocalnews/view/269760/1/.html. [Accessed 9 December 2009].

[25] S. J. Kang, K. Olmstead, J. Collins and K. Takacs, "Municipal Nutrient Removal Technologies Reference Document," United States Environmental Protection Agency Office of Wastewater Management, Washington D.C., 2008.

[26] T. Deen, "Developement: Singapore and Iraq- Contrasts in Water Management," 17 August 2007. [Online]. Available: http://www.asiawaterwire.net/node/570. [Accessed 9 December 2009].

[27] Australian Academy of Technological Sciences and Engineering, "Water Recycling in Australia," May 2004. [Online]. Available: http://www.atse.org.au/index.php?sectionid=597. [Accessed 9 December 2009].

[28] Asian Developement Bank Institute, "Successful Wastewater Management in Singapore," 2008. [Online]. Available: http://www.adbi.org/files/2004.06.28.cpp.waste.water.singapore.pdf. [Accessed 9 December 2009].

[29] Center for Justice, "Spokane River Project," 2004. [Online]. Available: http://cforjustice.org/river/spokane-river-project/. [Accessed 9 December 2009].

[30] State of Washington: Department of Ecology, "Spokabe River Dissolved Oxygen TMDL," State of Washington: Department of Ecology, Spokane, Washington, 2005.

[31] State of Washington: Department of Ecology, "Reducing Phosphorous," August 2009. [Online]. Available: http://www.ecy.wa.gov/programs/wq/nonpoint/phosphorus/PhosphorusBan.html. [Accessed 9 December 2009].

[32] Down to Earth, "Phosphate Soap Ban Garners World Attention for the Spokane River," 15 May 2009. [Online]. Available: http://www.downtoearthnw.com/stories/2009/may/15/phosphate-soap-ban-garners-world-attention-spokane/. [Accessed 9 December 2009].

[33] European Environment Agency, "Percentage of Total EU Expenditure on the LIFE Project from 1995 to 2006," 2006. [Online]. Available: http://www.eea.europa.eu/data-and-

maps/figures/percentage-of-total-eu-expenditure-on-the-life-project-from-1995-to-2006. [Accessed 9 December 2009].

[34] European Environment Agency, "Oxygen Consuming Substances in Rivers," 29 November 2005. [Online]. Available: http://themes.eea.europa.eu/IMS/ISpecs/ISpecification20041007131940/IAssessment1116505271445/view_content. [Accessed 9 December 2009].

[35] Spokane County, Washington: Water Resources Division of Utilities, "Nonpoint Source Phosphorus Assessment," 24 November 2009. [Online]. Available: http://www.spokanecounty.org/WQMP/content.aspx?c=1806. [Accessed 9 December 2009].

[36] European Commission, "Finance Programming and Budget," 2009. [Online]. Available: http://ec.europa.eu/budget/budget_detail/current_year_en.htm. [Accessed 9 December 2009].

[37] European Environment Agency, "Eutrophication," 1 May 2000. [Online]. Available: http://www.eea.europa.eu/publications/signals-2000/page014.html. [Accessed 9 December 2009].

[38] United Kingdom Environment Agency, "European Science Projects," 26 June 2009. [Online]. Available: http://www.environment-agency.gov.uk/research/library/science/33765.aspx. [Accessed 9 December 2009].

[39] State of Washington: Department of Ecology, "Data Summary: Spokane River and Lake Spokane (Long Lake) Pollutant Loading Assessment for Protecting Dissolved Oxygen," 8 October 2008. [Online]. Available: http://www.ecy.wa.gov/biblio/0303023.html. [Accessed 9 December 2009].

[40] University of Colorado at Boulder, "Cost Estimating," 2006. [Online]. Available: http://www.colorado.edu/engineering/civil/CVEN4434/resources/costs.html. [Accessed 9 December 2009].

[41] United States Environmental Protection Agency Region 10, "Authorization to Discharge Under the National Pollutant Discharge Elimination System," United States Environmental Protection Agency Region 10, Seattle, Washington.

[42] Food Magazine, "Addressing Australia's Wastewater," 14 January 2009. [Online]. Available: http://www.foodmag.com.au/Article/Addressing-Australias-wastewater/434786.aspx. [Accessed 9 December 2009].

[43] Washington Department of Ecology, "Spokane River Dissolved Metals," Spokane, 1999.

COLORADOSCHOOLOFMINES
EARTH • ENERGY • ENVIRONMENT

ENGINEERING MODERN VEHICLES FOR FIRST RESPONDERS

by Jennifer McClellan

When one thinks of firefighters, the first thing that usually comes to mind is a neighborhood home engulfed in fire. Perhaps that house is surrounded by firefighters in classic yellow suspendered pants and jackets hauling around fully pressurized hose with lights flashing and ladders being strategically placed. A less commonly considered scenario is that of the firefighter at the scene of a vehicle accident attempting to extract an inured passenger with an ambulance standing by to transport the victim to the hospital with a small window of time to save that person's life.

Although the first scenario is an honorable interpretation of the profession, it is also much less likely than the second. In reality, firefighters spend most of their time attending medical and vehicle collision calls and very little time actually fighting fires [1]. Training is a huge part of what they do and they are always focused on safety: safety for themselves, their co-workers and the public they are serving. This training traditionally covers fire safety of course, but also encompasses preparedness for all kinds of medical and accident situations in the home, in the streets and in the public in general. Many of these calls involve modern vehicles that have been in collisions. In 2013, the National Fire Protection Agency (NFPA) reported more than 31.6 million fire department calls. Only 1.2 million of those were for fires [1].

Unfortunately, making safety the top priority is making their jobs harder when it comes to modern vehicles and collisions of those vehicles. Many of the most popular and important safety features demanded by the consumers for their vehicles are increasingly more dangerous for firefighters and other first responders. Airbags, electric vehicle batteries, high-strength steels and push button ignitions are just a few of the new vehicle technologies that put first responders in danger.

Airbags have the potential to explode long after collisions are over when they are handled improperly. Airbags are being placed all over cars now, not just in the steering wheel and front dash. Some cars have them on or around the steering column to protect knees, side curtains to protect the head, sides of the seats to cushion against the door and even rear airbags in small smart cars that don't have substantial trunks. A fairly common new practice in vehicle production is the use of dual-stage airbags. These are designed to deploy in stages in an effort to adjust the amount of power released to avoid injury to the passenger [2]. This is amazing new technology to protect the consumers, but can be a real problem for first responders when the second deployment is significantly delayed, possibly due to a computer failure after a collision. No matter what the reason, it is extremely important for firefighters to be able to recognize the presence, location and type of airbags on any vehicle they come across very quickly. Without instant knowledge of this kind, airbags can threaten the lives of the rescuers and the car wreck victims when deployed unexpectedly.

Although hybrid and electric vehicles have significant advantages over the continued use of gas and diesel powered vehicles in terms of environmental responsibility, they also bring prominent safety concerns. Many of them require incredibly high voltages during operation. Voltages have gone from 12V to 375V or more in some cases, such as the Tesla Roadster [3]. It is critical that first responders know when they are dealing with these high voltages and how to handle them properly. It is even more critical that they are aware of this circumstance within moments of arriving at an accident scene. How a firefighter approaches and handles a vehicle will depend on the presence or absence of such a high voltage.

One of the first steps a firefighter is trained to take upon arriving at a vehicle accident scene is to ensure that the vehicle is not in gear and it is turned off [4]. With the use of more advanced technologies, many cars are nearly impossible to hear when they are running, making this first step more complicated. Now consider further the use of keyless, push button ignitions. Shutting the car down could potentially become impossible with damage after an accident. The danger is further increased if they are dealing with a high voltage vehicle [5]. This simple first step of verifying that the vehicle is not in gear and is not running is now much more complex on many new model cars with these features.

Wards Auto reports that newer high strength steels are beneficial in vehicle production in that they provide strength while keeping weight down [6]. Although this is good for performance, cost, marketability and passenger safety, it poses a unique issue to first responders in extrication situations. The metal becomes much harder to cut and can be beyond the capabilities of traditional extrication tools when used under traditional training practices. Difficulty in cutting in an emergent situation could result in cuts being attempted in improper locations, perhaps near an air bag that did not deploy in the collision. As a result, the rescuing firefighter and/or the vehicle passenger could be injured by the unintentional deployment of the air bag.

All of these features are intended to protect the consumers, reduce costs, increase safety and/or improve marketability. And in fact, that's exactly what they do. They are innovative, state of the art solutions that are sought after for convenience and safety. The engineers that have designed these features have done their jobs well, to a certain degree anyway. The electric and hybrid vehicles are designed with sustainability in mind while the advanced airbags are designed for passenger safety. Yet many of these features are not fully developed from start to finish. These are all hazards to first responders. Full development would include protecting passengers during a collision, police dispatched to the scene of the accident, firefighters extricating victims and tow truck drivers removing the wreckage.

Some vehicles have stickers and other exterior markings that are put in place during manufacturing with the sole purpose of notifying first responders of this kind of crucial information [7]. Unfortunately, most manufacturers do not do this and those that choose to do so voluntarily are under no obligation to follow any form of standardized labeling or notification.

Firefighters spend countless hours educating themselves on vehicle features and how to handle them quickly when lives are in jeopardy. Most of this training is developed by the firefighters for the firefighters. In many cases, this training is not initially set up because of someone’s foresight; it is developed because of some rescuer’s misfortune in a new kind of incident that no one predicted.

As engineers, we have an obvious motivation to create economically sound solutions that are socially and environmentally responsible. It is incredibly important to consider the full life cycle of the things we develop. Many would think through the life cycle of a car from production to consumer and consider the end of the life cycle to be a collision or recycling. However, the life cycle continues as long as individuals are in contact with the car, operational or not. We have a further obligation to consider the safety of those that protect us when we develop products that will ultimately be the responsibility of first responders.

At a bare minimum, vehicles should be subject to a standardized labeling system for these new technological hazards. This system should be easy to recognize, simple to understand for the trained individual and mandatory. Beyond that, the automobile industry should also feel an obligation to develop these features with firefighters in mind. Further, they should design back up methods for handling them that can be shared with the first responders.

The process of a firefighters unique injury or death leading to investigation by the fire service and new response methods for others that find themselves in the same situation in the future is backward. They should not be finding out about new hazards through injury and death of co-workers. They should be discovering new hazards from the people that are developing them in response to consumer demand in the first place.

Development of potentially hazardous safety and convenience mechanisms in the modern automobile industry should come with the expectation of full spectrum development. In other words, automakers should be obligated to provide resources, information and pre-determined procedures to the first responders that serve our communities.

We have a responsibility to consider the police, fire, ambulance and other public service members that keep us safe. This is both a public domain issue and a social consideration that should weigh heavily on the engineers that directly and indirectly affect them. Firefighters have excellent training skills and practices. We have an obligation, moral if nothing else, to help them in any way we can. Engineers should take more responsibility for their final outputs and help first responders to get back to what they originally intended to do.

References

[1] Fire Department Calls. National Fire Protection Agency. 2014 [online]. Accessed: http://www.nfpa.org/research/reports-and-statistics/the-fire-service/fire-department-calls/fire-department-calls

[2] Airbag Dangers Firefighters Face. Fire Rescue 1. Oct 11, 2011. [online] Accessed: http://www.firerescue1.com/firefighter-safety/articles/1168850-Airbag-dangers-firefighters-face/

[3] Berdichevsky, Kelty, Straubel & Toomre. The Tesla Roadster Battery System. Tesla Motors, Inc. Aug 16, 2006. v. 04.18.07.

[4] Protecting Our Rescuers. Midsouth Rescue Technologies. [online] Accessed: http://www.midsouthrescue.org/id14.html

[5] MCI's – When You're First on Scene. Firefighter Nation. Jul 23, 2012. [online] Accessed: http://www.firefighternation.com/article/special-operations/mcis-when-you-re-first-scene

[6] Weight watchers: aluminum, magnesium make gains as automakers reduce mass. Wards Auto. Sep 1, 1996, [online] Accessed: http://wardsauto.com/news-amp-analysis/weight-watchers-aluminum-magnesium-make-gains-automakers-reduce-mass

[7] Cars Safer for Passengers – But Not First Responders. USA Today. Aug 9, 2012. [online] Accessed: http://usatoday30.usatoday.com/money/autos/story/2012-08-08/car-crash-rescue/56885174/1

HIPS, KNEES, AND IUD'S OH MY!!

by Jeryl Sandoval

"We are not making cell phone cases here. We are making medical equipment that can affect people's lives." This fact was brought to my attention at the beginning of my training at Mountainside Medical by the Senior Quality Engineer. I was a quality engineering intern at a medical device manufacturing company, and I was to do things by the book of regulations that sat, tucked into the wall-mounted basket outside of the Document Control office... In the medical devise manufacturing field, the importance of producing high-quality equipment becomes glaringly obvious. Even medical device manufacturing giants have failed the public with faulty medical equipment – DePuy Orthopaedics' metal on metal hip implants, Zimmer Holdings Inc's alumina knee replacements, and Bayer's Mirena IUD – all three are examples of failed medical attempts resulting in painful complications. How did these failures come about? In the manufacturing world, success is a product of minimizing time and cost, while maximizing quality. An engineer in the manufacturing industry must grapple with balancing safety and quality assurance with maintaining practicality and profitability. Sometimes, this eternal struggle has resulted in bad products.

Unfortunately, a process that was created to expedite pushing new, innovative medical devices to market, the 510(k) program, has earned a reputation of being a way to cheat the system. The 510(k) program, also known as the "Substantial Equivalence in Premarket Notifications" program essentially allows a company to classify a new device as having substantial equivalence to a device that has already been in commercial production [1]. New technology, meaning technology developed after May 28, 1976, will always be initially be categorized as Class III. The classification systems work as follows: Class I devices are subject to general controls that are applicable to all devices, Class II devices require more stringent regulations than Class I, and Class III devices are those that require the general controls, additional regulations applicable to Class II devices, and a premarket approval [1]. Class III devices typically lack sufficient data to support the safety and effectiveness of the new technology. To reiterate, all new devices, created post adoption of the Medical Device Amendments in 1976 are categorized as Class III. This requires a company to invest much more time and money into rigorous testing, research, and paperwork. Usually, introducing a Class III device is only feasible for large companies, such as Johnson & Johnson or Bayer. This leaves little incentive for company to pursue innovation and production of better products. The 510(k) program was put in place to allow devices that are essentially identical in design and intended use to products already approved for commercial development to piggyback past the rigorous legal process necessary to develop medical equipment. This keeps innovation flowing and moves products to doctors and patients in a timelier manor.

A Class I device would be something like a tongue depressor that doctors use for a routine checkup [2]. Harmless, disposable, low risk—there is nothing wrong with expediting a new and improved tongue depressor through the legal system. A hip implant, on the other hand, is a Class III device. With side effects such as metal poisoning and painful dislocations, hip replacement technology is not something to be taken lightly. Hip replacements were first pioneered by John Charnley [3] in 1961. Charnley went through the trial and error process with Teflon, steel, dental cement, proper sizing for the acetabular cup and the femoral head, and failure. The breakthrough eventually came when Charnley was introduced to a new (at the time) polymer, HDPE. The modern hip implants used today are very similar to the design developed in the 1960's, but how similar?

DePuy Orthopaedics' metal on metal hip implants promised patients improved mobility, which spurred their popularity in the United States [4]. DePuy Orthopaedics, owned by Johnson & Johnson, cleared the Articular Surface Replacement (ASR) XL Acetabular system through the 510(k) program. A little detail was overlooked when this metal-on-metal hip replacement technology was cleared for commercial production and surgical implantation. Metal-on-metal did not improve mobility, as promised. In fact, friction between metal components was higher than the traditional metal-polymer and metal-ceramic designs. The increased friction on the metal-on-metal implants caused the ball-and-socket to grind and release particulates of metal into the surrounding synovial fluid. The loose metal particles could cause local damage to the surrounding bone and soft tissues, causing swelling and bone erosion. In some cases, the metal particles would enter the bloodstream. Once the metal particles entered the bloodstream, the body was susceptible to heart complications, thyroid disease, and neuron damage.

DePuy Orthopaedics has a serious problem arise with their seemingly substantially equivalent model of hip implant technology. By the time the recall had been issued, the damage had been done. The outcome was a recall for an estimated 500,000 hip implants across the United States and a lump sum of $800,000,000 [4]. The steps taken from initial complaint to recall took way too long, and there was no way to compensate individuals for the pain and suffering incurred due to the inadequate implant technology. Could this situation have been avoided? By sending the new technology through the 510(k) program, the device was not held to the rigorous standers that Class III device typically are. Simple details, such as increased friction between metal-on-metal ball and socket joints could have been prevented before thousands were implanted across the United States. By the time the case went to trial, DePuy admitted to knowing that more than 40 percent of the devices used would need to be replaced within five years of the initial surgery. With typical ceramic and titanium models lasting up to 15 years, the metal-on-metal fiasco could have been avoided, costing many patients their time, health, and quality of life, and the company millions of dollars and damage to their reputation.

The culprit of another prostatic fail is Zimmer Holdings Inc. Zimmer recalled both the Durom Cup hip implant and the NexGen CR-Flex artificial knee. Like the DePuy hip replacement model, the Durom Cup was a metal-on-metal rendition designed for patients eager for greater mobility. Ignoring the warnings of a highly regarded surgeon, the company continued to manufacture the implant, until finally accepting defeat [5]. However, the blame was to be passed to the surgeon. Zimmer claimed that the instructions for the hip replacement were inadequate. Similar problems occurred with the NexGen. Nine in one hundred patients who received the knee replacement surgery experienced failure in the device. This was in the form of persistent pain and looseness caused by a poor bond between the device and the femur [5]. Because of the technical responsibilities that an engineer holds, it is important, not only to create a functioning device, but to keep in mind the practicality of use and, in this case, installation. Even if the surgeons are to blame for improper installation, the problem could have been mitigated if the engineers at the company would have listened to the surgeons using their products and worked with them to create a more practical model.

The Mirena IUD is a product developed to provide women with a long-term birth control solution [5]. The device is implanted into the uterus and promises reliable, hassle free birth control from up to five years. Over 45,000 cases of unpleasant experienced have been received since the market release of the product in 2000. Just about everybody with cable has been exposed to the Mirena warning commercials. The issues with this device consist of organ perforation, and device migration, and expulsion, among other unpleasant side effect, which include back pain, breast pain, weight gain and acne. Perforations can cause debilitating pain, in addition to putting the person at risk for infections [6]. Device migration can lead to perforation in other organs, such as the lower intestine. The Mirena Lawsuit is a resulted from inadequate warning about the adverse side effects caused by the device [5]. Because of the inadequate labeling and warning associated with the Mirena IUD, many women have suffered painful, harmful side effects that could have been prevented. A company has the responsibility to warn the public about dangers associated with their products. As an engineer, it is important to think about the potential dangers of new technology and to be upfront with the risks. Hiding side effects behind misleading wording led patients and doctors to believe that the perforation and migration were only risks during the implantation procedure, which turned out to be false. Engineers should design to the best of their ability, and be honest with the associated risks.

…I was handed a box of defective parts, and it was made clear that attention to detail was the key to assuring product quality and thus, patient safety. I held a small metal jaw, with a light, rust colored stain, and turned it over and over again in my nitrile-gloved hand. What potential hazards can result from improper coating? What caused the problem? How can this error be removed from the manufacturing process? What if I just ignored it? These questions ran through my mind. I reached for the red tag and pulled the defective part from the sample population I was working with and took the jaw to my supervisor. Better safe than sorry. After all, the medical equipment leaving the shop floor would someday have a direct impact on somebody's life… Metal-on-metal hip implants, faulty knee replacements, and the Mirena IUD are all examples of the pain and suffering that can be induced by inadequate pre-marked research and testing, and refusal to take quick action when facing a serious recall-worthy product failure.

References

[1] Center for Devices and Radiological Health, "The 510(k) Program: Evaluating Substantial Equivalence in Premarket Notifications [510(k)]," 28 July 2014. [Online]. Available: http://www.fda.gov/downloads/MedicalDevices/.../UCM284443.pdf.

[2] D. J. Bach, Introduction to Biomechanical Engineering Lecture, Golden: CSM, 2013.

[3] John Charnley Trust, "Total Hip Replacements," [Online]. Available: http://www.johncharnleytrust.org/trust/thr.html.

[4] Drugwatch, "Hip Replacement Recalls," May 2014. [Online]. Available: http://www.drugwatch.com/hip-replacement/recalls/.

[5] Drugwatch, "Defective Medical Devices," 2014. [Online]. Available: http://www.drugwatch.com/medical-devices/.

[6] Aboutlawsuits.com, "Mirena IUD Lawsuit," September 2014. [Online]. Available: http://www.aboutlawsuits.com/mirena-iud-13909/.

COLORADOSCHOOLOFMINES
EARTH • ENERGY • ENVIRONMENT

THE UNIVERSAL DUTY OF THE ENGINEER

by Colton Sauer

There are many specialties within the field of engineering. Engineers can design a mass flow controller for a specific chemical reaction, a ceramic plate for a space exploration shuttle, or machines for an assembly line. However, there are certain considerations in engineering that cannot be avoided, regardless of the field of emphasis. The most important of these considerations are the ones with respect to ethics. Every engineering project will have ethical tradeoffs, usually including social, environmental, and economic interests. These tradeoffs are often in tension. For example, consumers may desire a more robust product because the current design may result in an increasing rate of injury for the end users. However, the manager of the project is required to keep the product below a certain price point, so the optimal solution to the problem cannot be implemented. This is an example of the tension between societal and economic pressures in the design process, which an engineer must balance in order to satisfy his or her ethical commitment within the engineering profession. Other examples of these ethical tensions are fracking as a petroleum engineer and gait and movement analysis of disabled patients as a biomechanical engineer. These two examples are discussed in greater detail to better understand tradeoffs that can occur while working on engineering projects.

The energy industry has recently gone through a resurgence to find home-grown sources of energy. For this reason, fracking for oil has grown in popularity over the last decade, and with that, has also seen an increase in its opposition. While drilling companies argue that fracking is a safe and effective way to retrieve natural gas, communities and activists see fracking as harmful for both the inhabitants and environment around the fracking site. These opposing views are the source for an ethical battle that has yet to be resolved.

As an engineer from Mines, I will be presented with ethical issues such as fracking. I will have obligations to my employer to complete the projects assigned to me, but more importantly, ensure safety for the end users of my product or design. This obligation is explicitly stated in the Engineer's Code of Ethics: "Engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public" [1]. There are more canons listed in the code of ethics, but this statement is listed first because it is the most important obligation for a professional engineer. Engineers are also accountable for producing sustainable designs in order to better preserve the environment. Fracking is considered an ethical issue because it is both satisfying

and opposing portions of the code of ethics simultaneously. For example, fracking betters the welfare of the public by producing more jobs and benefits the local economy by providing lower-cost natural gas. However, fracking allegedly destroys the environment and harms those near the fracking site due to the seeping of toxins into the ground from the fluid. In order to be a successful engineer, one must tread carefully in order to respect the opinions on both sides of the argument.

An engineer also has an obligation to his or her employer in order to produce a functional end product or design. If I were hired as an engineer for a fracking project I would have to grapple with the two opposing viewpoints for fracking. A cost-benefit analysis would most likely show if a fracking project was feasible. Of course, if fracking is banned in the location, then no operations will take place. However, if it is legal in the location with active opposition, then I will need to use cost-benefit analysis to determine if pursuit of the project is worthwhile. The benefit of this project is the influx of natural gas to distribute, as well as employment for local citizens. The cons of this process are the extremely large amount of water and other fluid that is necessary to extract the gas, as well the potential contamination of the surrounding groundwater due to the carcinogenic nature of some of the chemicals used in the process. However, "the EPA has publicly stated that [hydraulic] fracturing does not pose a significant threat to groundwater" [2]. Therefore, unless environmental activist groups pursue legal action to prevent the fracking, I would most likely work towards completing the project. In this instance, there is a beneficial economic impact, negligible environmental impact, and typically negative social impact. As engineers, it is our responsibility to impartially weigh the tradeoffs between each of the considerations without being influenced by outside sources, such as the media. The media has typically cast fracking as a negative activity, but realistically the benefits of the process can outweigh its risks.

My area of expertise lies within biomechanical engineering, which is quite different than the oil and gas industry. However, biomechanical engineering results in similar, if not more difficult, ethical issues than what is seen in oil and gas. The increased ethical difficulty is because this engineering directly impacts the health of individuals, not indirectly through possible seepage of toxins into groundwater. Decisions made by a biomechanical engineer will affect the treatment of a patient. The perfect example of this is my work with Children's Hospital Colorado.

I worked as an engineering intern for the Center for Gait and Movement Analysis. In this lab we tracked the walking motions of children using infrared cameras. These children were often suffering from neuromuscular diseases like cerebral palsy and muscular dystrophy. My work as an engineer was to assist the technical team retrieve this walking data, and retrieve information such as joint angles, torques, and powers. This information was used in a weekly meeting to help determine the best treatment plan for these children. The most common form of treatment for these patients was surgery to repair muscle or bone defects. This conventional form of treatment is the why I must hold the first canon of the Engineer's Code of Ethics paramount. My decisions within the laboratory are directly impacting the health and wellbeing of its patients.

Decisions made while working as a biomechanical engineering should not be taken lightly. Treatments can have diverse outcomes, both adverse and beneficial. A common example of this is children with cerebral palsy because they are historically hard to treat. Conventional treatments are not guaranteed to have positive outcomes. Some risks of surgeries include no change in walking ability, inability to rehabilitate, and repeat surgeries to repair the initial, ineffective procedure [3]. The information that we derive from the patient data will be used by the orthopedic surgeons to determine the best course of treatment, so unlike most other engineers, we are assisting in the decision for medical intervention. Whenever medical intervention for a patient is involved, the code of ethics must be followed even more closely. This is why there are so many regulations with respect to patient safety and confidentiality when a patient is treated or studied in a medical setting.

However, there is also a social aspect to our work as biomechanical engineers. The least invasive of treatments is to prescribe ankle foot orthotics. These are generally quite visible ankle braces that the children will have to wear whenever they are walking to provide additional support to weak body structures. Even though the orthotic designs will usually improve a child's ability to walk, these patients often fail to comply with the physician's wishes to wear the orthotics. The children often see the orthotics as a tangible manifestation of their disability. Social pressures, just like in other fields of engineering, can impact the effectiveness of a design. If the design is adopted by society, then the design is much more likely to meet its goals with less opposition. However, like in this case, the orthotics make the patients feel like they fit less into societal norms than before, so there is an increase in opposition from the end user of the design. It is the engineer's responsibility to address these issues to produce a more successful design. For this example, a way to increase acceptance is to either make the orthotics less noticeable or to make it desirable for the children by adding extra features like superhero prints to the plastic.

In the world of medicine, end user needs are typically addressed on an individual basis instead of the community as a whole. In natural gas fracking, it is the opposite. Activist groups and communities often mobilize to try to stop this drilling method. Economic and environmental considerations are also in tension with the aforementioned societal issues. It is the engineer's responsibility to weigh each of these considerations in the final design or project. A successful engineer will adhere to as many considerations as possible while producing a safe and economically feasible design. Tradeoffs between each of these considerations is inevitable while working on engineering projects, and it is the engineer's duty to properly account for each one and produce the optimal design, regardless of the field that engineer is working in.

References

[1] National Society of Professional Engineers, "Code of Ethics," July 2007. [Online]. Available: http://www.nspe.org/sites/default/files/resources/pdfs/Ethics/CodeofEthics/Code-2007-July.pdf. [Accessed 21 October 2014].

[2] L. Fuller, "Fracking Technology Has Been Used Safely for Years," 28 November 2011. [Online]. Available: http://www.usnews.com/debate-club/is-fracking-a-good-idea/fracking-technology-has-been-used-safely-for-years. [Accessed 21 October 2014].

[3] "Types of Surgery," [Online]. Available: http://cerebralpalsy.org/about-cerebral-palsy/treatment/surgery/types-of-surgeries/. [Accessed 23 October 2014].

THE WORLD CUP, IT'S NOT ROCKET SCIENCE

by Jace Warren

The World Cup is a soccer tradition that takes place every four years. It is a tournament that is played by national teams to prove who the best country is in terms of soccer and is hosted by a selected host country. The United States hosted the 1994 tournament in Pasadena, California. There is a huge economical advantage to hosting the World Cup since it is such a large event that brings people together from around the world. I was in South Korea when they hosted the 2002 World Cup. Seoul is a very densely populated city as it is and with all of the fans pouring in from around the globe, it was nearly impossible to get anywhere. So much so that for the majority of the games, we did not try and go anywhere. The World Cup does bring with it the economic boom, but it also puts a strain on the host. The host country needs to be able to properly house and support not only the teams, but also the fans. Because of this, the host nation is awarded the hosting position several years in advance in order to prepare for the event. New stadiums are built, housing is constructed, and the city can prepare for the economic impact.

Countries can put in bids to be the host of the World Cup, much like the Olympics. The countries are given requirements that are expected in order to make them a stronger bid. Once a bid has been placed, a group of FIFA inspectors come to the country to evaluate the state of the country and whether or not it is able to host such an event. FIFA's executive committee then votes on the countries that had placed bids and a host nation is selected.

In 2010 the host countries for the 2018 and 2022 World Cup were selected. The winning countries were Russia and Qatar, respectively. Qatar has recently become the richest country in the world and is trying to make a name for itself by hosting the World Cup. It has already started making way on building several state of the art stadiums and facilities. Although it has the economic ability to be able to host such an event, there have been multiple attempts to get the bid overturned. This is due in large to the environment of Qatar. The World Cup games are played during the summer where temperatures can regularly be over 120 degrees Fahrenheit. Although the plans for the stadiums will take this into account by cooling the fields, it does not help out the fact that all the fans and workers from around the world will have to endure this harsh environment. This seems like a small issue for such a large event but it has larger consequences.

Qatar has a long history of bad conditions for labor workers. Being such a small country, most of its labor force is brought in from surrounding countries such as the Philippines and India.

"There are 1.4 million migrant workers in Qatar — the tiny, oil-rich Arabian peninsula that won the right to host the 2022 World Cup. Many of these workers came from poor regions of Southeast Asia, and they work under an archaic system called kafala that human rights watchers call "modern-day slavery." These workers can't leave the country without an exit visa. And they can't get an exit visa without their employers' approval." [1]

The conditions for these workers are very poor. They are put into housing that cannot adequately house and support such numbers. They are forced to work long hours in the extreme environmental conditions. They get paid little to no money and have almost no rights. Although the Qatari government has not reported any deaths of its work force, many other sources have. The Pravasi Nepali Co-ordination Committee has reported that more than 400 migrant workers from Nepal have died since Qatar won the bid for the World Cup [2]. The Indian embassy in Qatar has reported that over 500 migrant workers from India have died working on World Cup projects since 2012 [3]. "FIFA cannot simply look the other way. Football's governing body should be leading demands for change, not dragging its feet" says Jim Murphy, the shadow international development secretary.

So what should be done? The conditions are not going to be getting better anytime soon for the migrant workers. The engineers being brought in are being very well paid and are living comfortably so they are not complaining. The Qatari government is not concerned about any of this. The migrant workers are coming in from some of the poorest places in the world willingly so their government cannot do anything about it. FIFA has still not done anything to stop this and rumors of corruption are endless. So who needs to take responsibility and fix what is going on? There seems to be no solid answer for this. People are demanding that the games be moved immediately so this kind of treatment of workers will stop.

How does this affect us as engineers, though? What impact can we have on such issues? I decided to get into engineering because I wanted to avoid politics. But as I began getting closer and closer to becoming an engineer, I realized that was impossible. I just wanted to build the biggest buildings and engineer the worlds most advanced cities. So when I learned that the company I was working for part time was engineering the stadiums for the World Cup in the richest, fastest growing country in the world, I immediately applied. The plan was for me to graduate and then start my career in Qatar making a name for myself. The more it started looking like a reality, the more I became excited. But as I looked into it more and more, that excitement became disappointment. The conditions for the migrant workers were a huge concern of mine. The rumors of what was going on made me rethink my dreams. I was told not to worry about that, I would be well taken care of over there, both financially and in my working conditions. But that was not the type of engineer I wanted to be.

Wernher von Braun is probably best known as the "Father of Rocket Science." He worked for the Nazis developing combat rockets during World War II. He developed and helped produce many combat rockets during his years with the Nazis, but his true passion was in space exploration. After the war was over, Braun surrendered to the US and was brought on as an American scientist, once he was "cleansed" of the Nazi party. He would eventually work for NASA and played a large role in landing the first men on the moon. He was a brilliant man and a great scientist, even though he was a Nazi. He advanced rocket science more than anyone else ever has. Does this make up for his time with the Nazis though?

Tom Lehrer wrote a song called Wernher von Braun in 1965. One of the lines in that song goes: "Once the rockets are up, who cares where they come down? That's not my department', says Wernher von Braun." Is that the mentality that scientist and engineers need to have, or do we need to be held to a higher standard. He was in charge of getting the rockets in the air, not bringing them down.

So what about the engineers building the stadiums in Qatar? Do they need to be concerned with the migrant workers, or is that not their department? Where do we draw the line between doing our job and standing up for something that is right? It is easy to justify the fact that the engineers are just doing their jobs. It is hard for somebody to stand up and take responsibility for what is going on.

Braun was just chasing his dream of the stars, feeding his thirst for knowledge, and will go down in history as one of the best scientist in his field. But he will also go down in history as a Nazi. Building stadiums is a lot different than designing rockets for the Nazi party, but Braun and I were in the same position. He was not directly killing people; he was just making advancements in rocket science. I would not be responsible for the deaths of all the migrant workers; I would just be helping design the stadiums they would have to build. His name is on those rockets, and mine would be on that stadium, just like my dream. Can I say that as an engineer, they do not matter to me, that it is not my department? It is a difficult question to answer and it is different for everyone. It is important to learn from the past in the field of engineering and science, though. That is why when the recruiter for the project called I turned down the interview.

References

[1] Manfred, Tony. "The Shockingly Awful Living Conditions Of Construction Workers In Qatar Before The 2022 World Cup." Businessinsider.com. N.p., 3 June 2014. Web. 22 Oct. 2014.
[2] Doward, Jamie. "Qatar World Cup: 400 Nepalese Die on Nation's Building Site since Bid Won." Theguardian.com. N.p., 15 Feb. 2014. Web. 22 Oct. 2014.
[3] Gibson, Owen. "More than 500 Indian Workers Have Died in Qatar since 2012, Figures Show." Theguardian.com. N.p., 18 Feb. 2014. Web. 22 Oct. 2014.

ANALYSIS OF THE SOCIAL AND ECONOMIC CONSIDERATIONS IN CIVIL ENGINEERING

by Preston Wierzba

Civil engineers provide services to design and maintain public works such as roads, bridges, water, and energy systems, as well as public facilities like ports, railways, and airports [5]. Civil engineering as a whole faces a great challenge of balancing social, environmental, and economic considerations by creating designs that best serve the public at a low cost and with the least environmental impact as possible. It is not feasible to meet all three of these criteria perfectly in a design, and in many cases, it is difficult to even conquer two of these challenges without even taking into account the third. The two challenges that civil engineers face the most in designs are the social and economic considerations. In many cases, these two challenges have to be balanced during the design process based on the client's wants and needs. Making compromises between a design's cost and functionality is frequently the solution, which means that sometimes one has to be sacrificed for the other.

The social considerations of a civil engineering design can imply many things including functionality, public safety, sustainability, and the construction process. The functionality of a design is how well the design serves the purpose of being able to solve a specific problem. This is usually developed and requested by the client, but it is the responsibility of the civil engineer to ensure that the design meets that function and behaves the client wants. The public safety of a design is also an important social consideration because it makes sure that the general public is not at danger to the use of a design. This requires a civil engineer to ensure that failure does not occur in a structure or other design based on well-established building codes. Another social consideration that must be accounted for is sustainability, which ensures that a design is able to function throughout its specified lifecycle and that it is able to be maintained appropriately. Finally, the construction process is an important social consideration because it requires community involvement and interaction. This list does not include all of the possible social considerations in a design, and each one is not necessarily involved in every design. However, these are the most frequently occurring social considerations in most civil engineering designs, and they each add their own element of complexity to a project.

In addition to social considerations, civil engineers also need to pay special attention to the economic feasibility of their designs. This typically depends on the type of client for the project the amount of funding that they are putting towards the design. In many cases civil engineers provide designs and solutions for the government. Some of these types of projects include roadways, water management projects, and utility designs and modifications. In such cases where a branch of the government is the client, the project funding is provided by taxpayers. Although it is the duty of a civil engineer to provide the design specified by the client, it is also in the best interest of the taxpayers for the design to cost the least amount possible. Determining the budget is primarily the responsibility the client, but it is also the responsibility of the civil engineer to stay under budget. This sometimes comes at the cost of reducing size or eliminating features that decrease the functionality of the design.

When looking at the budget for a civil engineering project, there are two major types of expenses: the consulting costs and the building costs. The consulting costs account for the architectural and engineering designs as well as the site testing and analysis. The building costs account for the labor and materials required for the project. Consulting fees vary between different types of projects, but typically do not account for more than 10% of the total project cost [4]. Although it is only a fraction of the construction costs for a project, the consulting fees help ensure that the social considerations of a design are being met, especially for functionality and public safety. Consulting fees can also help ensure that the whole project does not end up over budget by taking time to find a balance between cheap materials and a sufficient design that meets the client's needs. Consulting fees are very important for a successful design, but there is a limit to how much good they can do as the fees get higher.

A great example that displays the tradeoffs between social and economic considerations in a civil engineering project is the Big Dig project in Boston. The project began in 1991, and was intended to replace many outdated freeways and bridges and build new roadways that would help improve traffic. The most important part of the project involved the replacement or a 6-lane freeway that ran through the middle of the city, known as the Central Artery, with a wider underground tunnel. The goal for the project was to improve the terrible traffic situation that Boston was currently experiencing as well as burying the eyesore of a highway that ran through the middle of the city, which were both social considerations that civil engineers had to take on [3]. The megaproject involved many aspects of civil engineering including: structural engineering for the bridges, geotechnical engineering for the tunnels, transportation engineering for the traffic patterns, water resource engineering for the water containment, and environmental engineering for the mitigation of potential environmental impacts of the project. The project initially had an expected cost of $8 billion (taking into account inflation to the time of completion) and an expected completion time of eight years [1,2].

The duration of the Big Dig project saw many changes in plans and many unexpected circumstances that increased the price and time of construction from the original estimates. The lack of pre-planning resulted in the largest unforeseen costs. One example is that one designed tunnel section connecting Interstate 90 to the new Ted William's tunnel could not be built according to its design due to negligence in the planning stages. The environmental impact statement had planned to float in parts of the tunnel which, in reality, could not be done due to low bridges along the waterfront. Plans had to be changed for it to be constructed in parts, which resulted in an increase in the schedule and a major increase in costs [3]. In the end, the majority of the plans for the project had been executed, but it had run over schedule and over budget. The project was completed in 2005, six years later than scheduled, and the total cost was approximately 14.8 billion dollars, over $6 billion more expensive than was initially planned. One factor that should also be noted is that a substantial amount of funding was borrowed for this project and the total cost estimate for the project including interest is $22 billion [2]. Even though the costs ran high, the project turned out to be a success and an incredible feat of engineering.

The Boston Big Dig project was determined to solve the social considerations of the traffic problem, and as a consequence, took a hit in the economic considerations of the project. The engineers had to deal with tough soil conditions and difficult challenges, and it was determined that the desired functionality could only be achieved through a high cost solution. One way to mitigate some of the budget and schedule increases that occurred would have been to increase the amount of consulting and pre-planning work done prior to construction. Although this would have required more funding during the initial stages of the project, it would have saved money in the long run, especially since so much money had to be borrowed to complete the project.

Professional civil engineers are not only required to know design skills, but are also required to know how to manage designs based on social and economic considerations. These two types of considerations are going to be present in any project because there is never an unlimited budget. It is essential for a civil engineer to get to know their client, and determine which type of consideration outweighs the other. If the social considerations outweigh the economic considerations, it may be required for the project to go over budget, which was the case in the Big Dig project. If the weight of each consideration is the opposite, the functionality of the design may have to be reduced in order to meet the budget. As time goes on, new creative ideas continue to be developed and spread across the civil engineering industry which creates opportunities to develop designs that meet the desired functionality and budget specified by the client. Being able to manage social and economic considerations is what makes a good civil engineer, but is not absolutely required for the profession. The most important job of a civil engineer is to create safe designs that will not fail in order to protect the community that the design is being made to serve.

References

[1] Completing the "Big Dig": Managing the Final Stages of Boston's Central Artery/Tunnel Project . Washington, DC: The National Academies Press, 2003 .

[2] Gelinas, Nicole. "Lessons of Boston's Big Dig." City Journal. Manhattan Institute, Autumn 2007. Web. 21 Oct. 2014. <http://www.city-journal.org/html/17_4_big_dig.html>.

[3] Lindgren, Alan. "Boston Big Dig." Extreme Engineering. Dir. Sarah Holt. Discovery Channel. 28 May 2003. Television.

[4] Strauss, Eric. "Are Engineering Fees a Percentage of Construction Costs?"Small Business. Demand Media, n.d. Web. 22 Oct. 2014. <http://smallbusiness.chron.com/engineering-fees-percentage-construction-costs-51642.html>.

[5] "What Is Civil Engineering?" American Society of Civil Engineers. N.p., n.d. Web. 21 Oct. 2014. <http://www.asce.org/>.

Notes

1	S14-04	AUTOBOTS
2	S14-05	SOLTREK
3	S14-06	AERO PEAK
4	S14-03	JALAPA NICARAGUA
5	S14-07	6DOF TEST FRAME
6	S14-02	CSM OUTREACH
7	S14-08	ACTIVE AERO
8	S14-09	HIGH DATA RATE PULSER
9	S14-01	FLIGHTBULB