MIE CAPSTONE DESIGN PROJECTS

2018 — 2019

Mechanical & Industrial Engineering
UNIVERSITY OF TORONTO

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The MIE Design Showcase is a momentous occasion for our students.

This event represents a culmination of their four years of engineering academic studies, as they present their final engineering design solutions in front of their peers, their professors, alumni and industry representatives. As 490/491 course coordinators, today is a point of pride for us as well.

Each year, we are privileged to witness our MIE students step up to the challenge and design solutions to complex, real-world industry problems with an impressive degree of engineering acumen and deep collaboration. This year, our students worked in teams to complete 68 projects. The projects are diverse, the results are astounding, and the impact is real.

To our industry partners, we thank you for your commitment to our students and to our mission of providing them with the knowledge and skills to practice engineering design. Their success would not be made possible without your continued, unwavering support of our department and students.

We would also like to thank our faculty supervisors for the guidance and expertise provided to this year's capstone teams, as well as staff who helped coordinate the course and today's event. To our students, we congratulate you on your design achievements on display this evening.

We look forward to another year of academic-industry collaboration, and once again celebrating our students' designs at next year's showcase.

Dionne M. Aleman
Associate Professor

Kamran Behdinan
Professor
NSERC Chair in Multidisciplinary Engineering Design
Director, U of T Institute for Multidisciplinary Design and Innovation (UT-IMDI)

Advanced Industrial Technology

A Portable, Buildable Mechanical Testing Machine for Undergraduates

Client: Professor Jason Foster
Team Members: Monica Burgers, Xinyue Liu, Simo Pajovic, Chi Zhang
Supervisor: Beno Benhabib

A mechanical tester students can build at a fraction of the price

To support recent paradigm shifts in engineering education from passive to active learning and a desire to improve undergraduate laboratory work, we have developed an open-source, multi-functional universal mechanical testing kit (UMTK) for first year engineering students. Modeled after industrial test equipment, the UMTK is a dual-column, translating crosshead mechanical tester made from inexpensive parts sourced from reputable suppliers such as McMaster-Carr and AliExpress. The frame consists of T-slot aluminum extrusions, providing both strength and ease of assembly. The UMTK includes three swappable end effectors, allowing students to perform tensile, compression, and flexural tests. To record data and control the system, we used an Arduino Mega, a microcontroller commonly found in open-source hardware. We coded a simple user interface in Python, a language first years will know from their computer programming course. Students can observe plots of force against extension in real time and export the data as a CSV file for analysis.

Giving students the power to develop hands-on skills wherever, whenever

Growing issues with the costs of lab equipment, space, and coordinating the use of existing equipment at universities have limited students' opportunities to interact with real machines and thereby learn and understand engineering practice. Our design addresses these issues by providing students with a transparent kit from which they can assemble a fully functional universal mechanical tester, allowing them to perform tensile, bending, and compression tests on materials and parts as part of their coursework or for design teams and personal projects. Moreover, we believe the UMTK supports curriculum integration; we envision it enabling students to bridge the gaps between courses in materials science, solid mechanics, product design, and even mechatronics and coding. Ultimately, the UMTK will equip students with the hands-on experience necessary to solve the challenging real-world problems they will encounter as professional engineers.
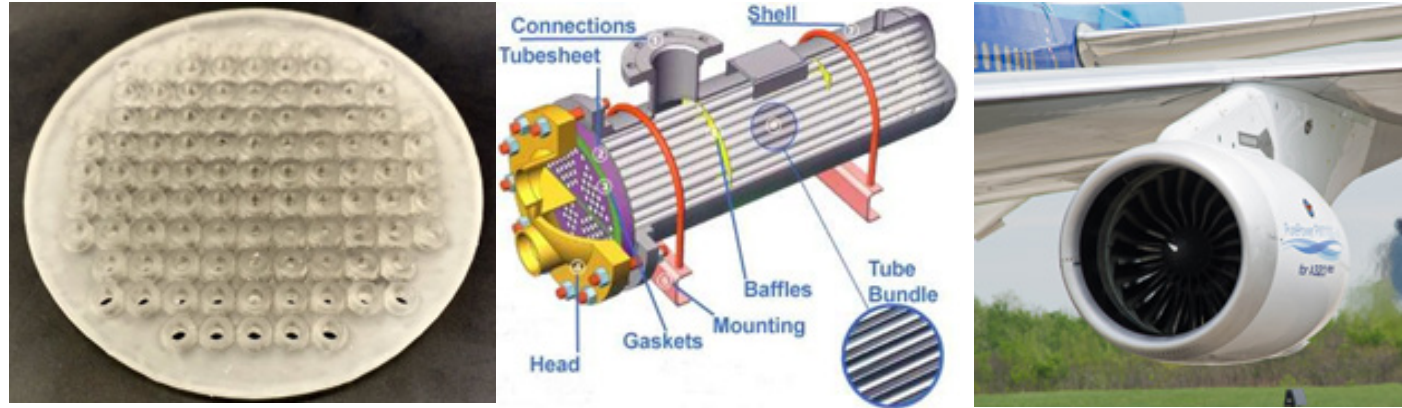
Additive Manufacturing of Heat Exchanger Tubesheets

Client: Pratt and Whitney Canada
Team Members: Sameed Akber, Yingman Chen, Han Wang, Nebojsa Jovanovic
Supervisor: Hani Naguib

3D printing tubesheets for aircraft shell and tube heat exchangers to cut down on labor costs and manufacturing times

One of the fundamental parts of an aircraft engine is a shell and tube heat exchanger. Traditionally, CNC drilling is required to drill holes into a tubesheet at programmed locations. Tubes are fit into the holes and manually expanded for proper sealing. This process is labor intensive and time consuming. Pratt and Whitney Canada has tasked our team with developing a method for 3D printing tubesheets. Such a process will allow printing of tubesheets that are able to fit tube bundles with tubes of any shape and in any pattern. This will mean more flexibility in heat exchanger design. Looking beyond aircraft engines, this method will also prove useful for manufacturing heat exchangers for electronics.

Scanning tube bundle to manufacture custom fitted tubesheets

The process starts with the tube bundle. Tubes are scanned and the scan is developed into a 3D model of the tubesheet. This model is then analyzed. Once analyzed, the model is sent to a 3D printer. The printed tubesheet is then joined with the tube bundle to complete the assembly. Integration of a novel scanning technique in the manufacturing process will allow tubesheets to be printed to fit tubes irrespective of the shape of the tube bundle. A tubesheet prototype manufactured using the proposed process will be showcased along with a time-lapse of the complete manufacturing and assembly procedure. Results of engineering analyses of the tubesheet will also be presented.
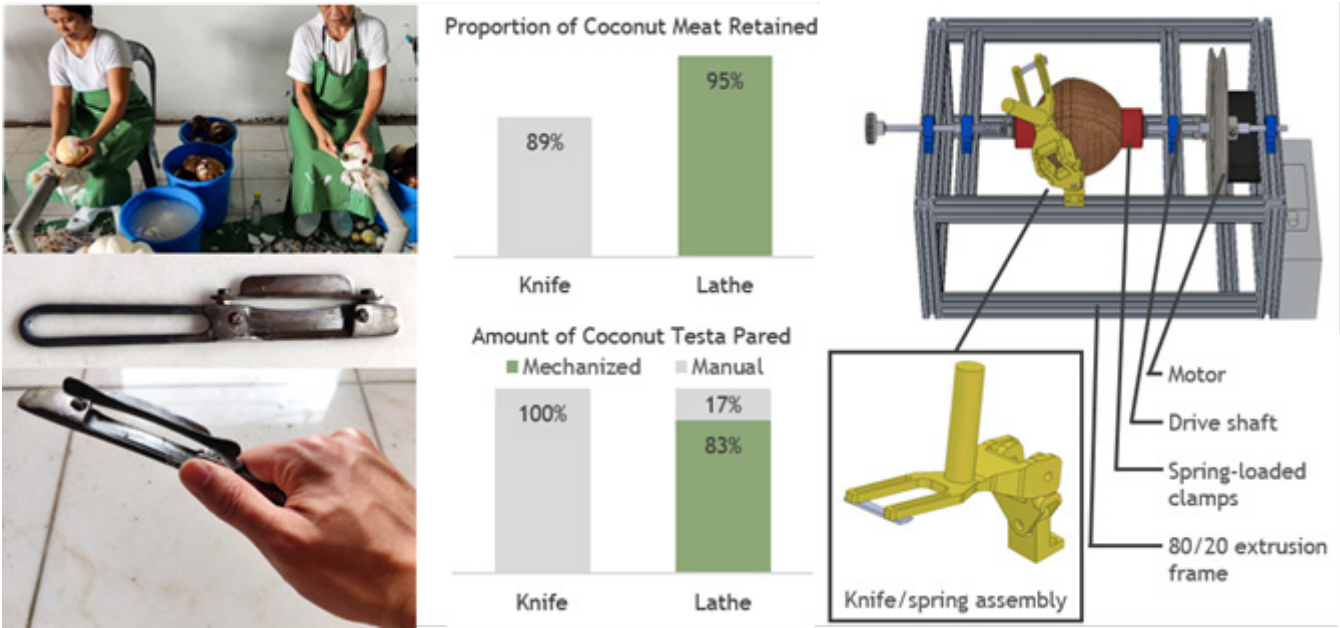
Coconut Lathe: Efficient Paring in Rural Philippines

Client: CocoAsenso
Team Members: Hema Nookala, Maria Reuben, Aldrin Perez, Chuzhang Han
Supervisor: Amy Bilton

Optimizing Production for a Social Enterprise in the Filipino Coconut Industry

CocoAsenso is a social enterprise producing desiccated coconut, based in Samar, Philippines. With factories in remote areas, they seek to increase profits and jobs for local farming communities.
Paring the skin (testa) of the coconut is strenuous and difficult. Our design aims to:
- Increase efficiency and output
- Increase ease of use
- Increase testa removed and coconut meat retained

Delivering a Locally-Driven Design Solution

- Mechanizing the paring process reduces physical strain and the training required by lessening demand on dexterity
- Main features:
  o Spring-loaded clamping mechanism
  o Rotational mechanism with variable speeds
  o 2 degree-of-freedom paring knife and spring assembly
- Higher paring efficiency for majority of the surface area; integrates well with manual paring to remove remaining testa during quality control
- Designed for locally-available materials and equipment, and with main components which can be easily replaced

Bringing Opportunities and Profit to the Rural Farming Community

- Removing thinner pieces of testa results in 6% more meat retained, increasing profits
- Removes 100% of the testa, maintaining the current quality of output while reducing manual effort by 83%
- Increases output and adds scalability in the process to create jobs
- Aligns with client's social enterprise goals to bring profits and opportunities to rural communities
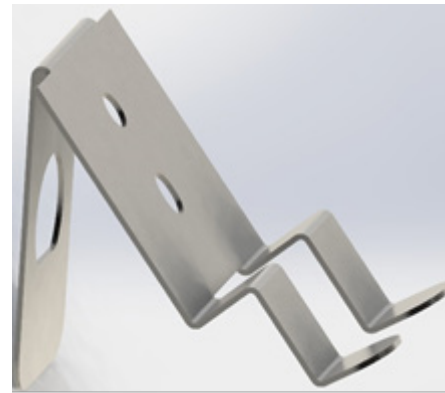
Figure 1: Bending Part
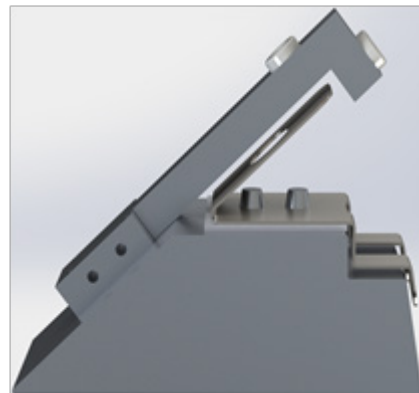
Figure 2: Checking
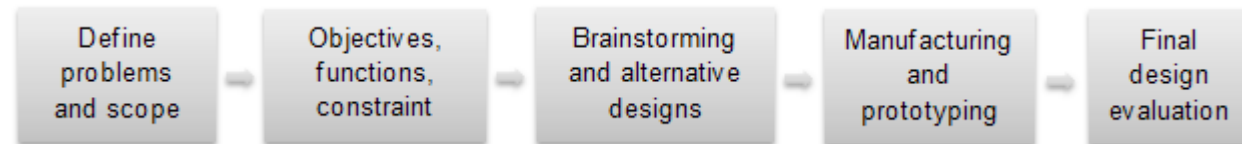
Figure 3: Flow chart of the design process

Design an Educational Lab with Advanced Bending Machine

Client: Ryan Mendell
Team Members: Linhan Yu, Henghao Zhang, Ni Yi, Lu Jiang, Songhui Xu
Supervisor: Anthony N. Sinclair

Client's Need & Impact: Bring Advanced CNC Technology to Students at the University of Toronto

As the computer numerical control (CNC) technology has been significantly implemented in the manufacturing industry, students will benefit from learning this advanced technology in their academic careers. The machine shop manager has requested a Capstone team to design a lab session that teaches students the metal bending principles using the CNC brake press. The purpose of this Capstone project is to develop a sheet metal part, a checking fixture, and a complete lab session.

The final deliverable of this lab session will be a detailed instruction that guides students through the standard design procedures for CNC brake press bending parts and usage of checking fixtures. On a broader scale, students will be equipped with the fundamentals of advanced manufacturing technologies from this lab session. As a result, mechanical engineering students at the University of Toronto will be more capable of designing creative bending parts, which increases their competitiveness in future job-hunting. Moreover, manufacturers will also benefit from this project as more well-trained students in operating CNC brake press are available in the future.

Result: Advanced Fabrication for CNC Break Press Bending Parts and Checking Fixtures

The design process is divided into five steps indicated in figure 3. During the evaluation process, we used pairwise comparison and weighted metrics to compare all the alternatives and selected the final proposed design.

The most innovative parts of the final design are the multifunction of the cell-phone holder and two dimension checking methods for the checking fixture. The cell phone holder which can also be used as a bottle opener are shown in figure 1. Based on the dimensions of the bending part, the team fabricated the checking fixture shown in figure 2. For the most crucial angle and length, 2 statistical process control (SPC) indicators are used for higher accuracy while the rest of the dimensions are measured by a feeler gauge which is faster and overall reliable.
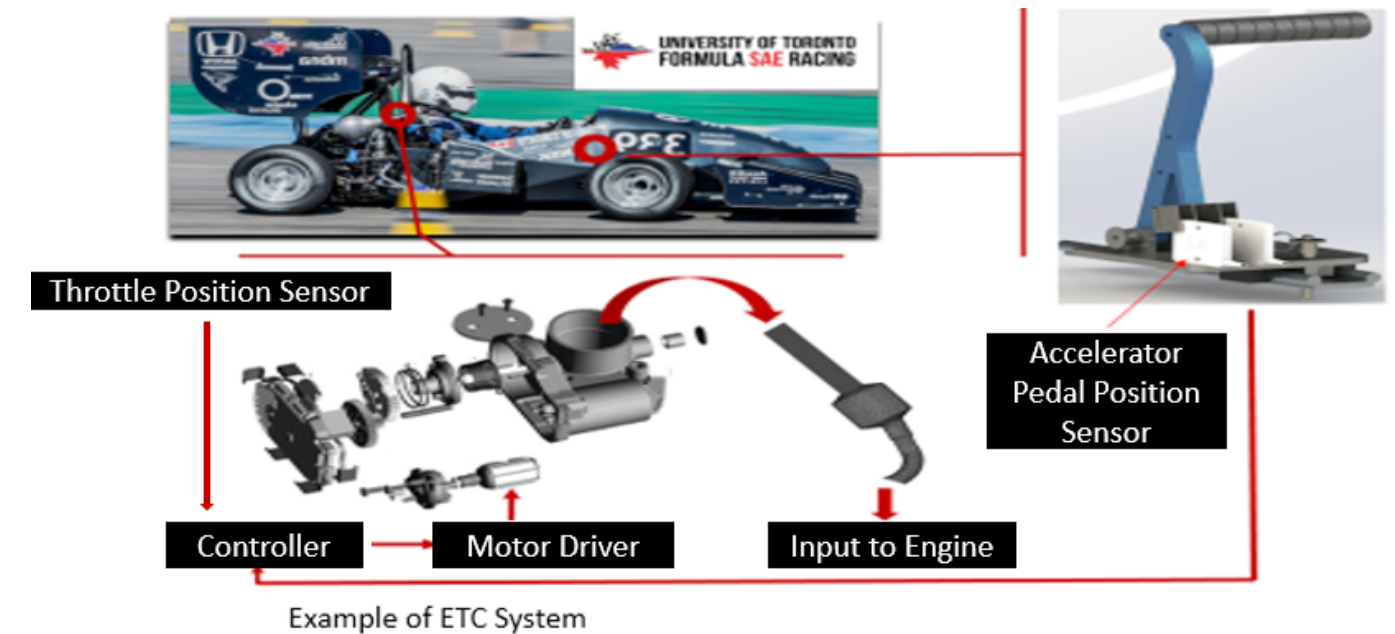
Electronic Throttle Control (ETC) for FSAE Vehicle

Example of ETC System

Client: Formula SAE Racing Team (U of T)
Team Members: Arham Danish, Kihyun Cho, Rafid Khan, Sameer Khan
Supervisor: Eric Diller

Motivation and Impact of ETC System

The Client is seeking a replacement of their existing Mechanical Cable Throttling system which controls the flow of air into the engine for combustion. It operates on open-loop principles and hence does not provide feedback to detect and correct errors. The client needs a tunable system that can modify throttle responses to prevent engine damage and improve racing performance affected by aggressive racing styles.

A platform for electronically-controlled throttle system has been developed to address these issues. Other global FSAE teams who rely on conventional throttle control systems may also be able to overcome these challenges with the proposed solution. In addition, the developed solution can serve as a model platform to improve the throttling performance for any class of racing vehicles.

ETC Design Overview and Key Parameters

The proposed ETC control system first registers the user's input through the Accelerator Pedal Position Sensor (APPS) and sends a control signal to the motor to actuate the throttle plate. Then, the Electronic Control Unit (ECU) receives feedback from the Throttle Position Sensor (TPS) to adjust the output control signal. The solution is distinct from other commercial automobiles' ETC systems in that it can be developed on any ETC throttle body and be strategically tuned for racing conditions. The PID Control system involved utilizes mathematical models to determine constants characterizing error terms and to correct any deviation of the output from ideal responses. Furthermore, the Team provided the client with easily tunable parameters below, that are showcased in a working prototype:

- Throttle sensitivity change in various RPM ranges
- Pedal and throttle plate relationship modification
- Safety Protocols

Current Design

Design A: Multiple Scales

Design B: System Optimization
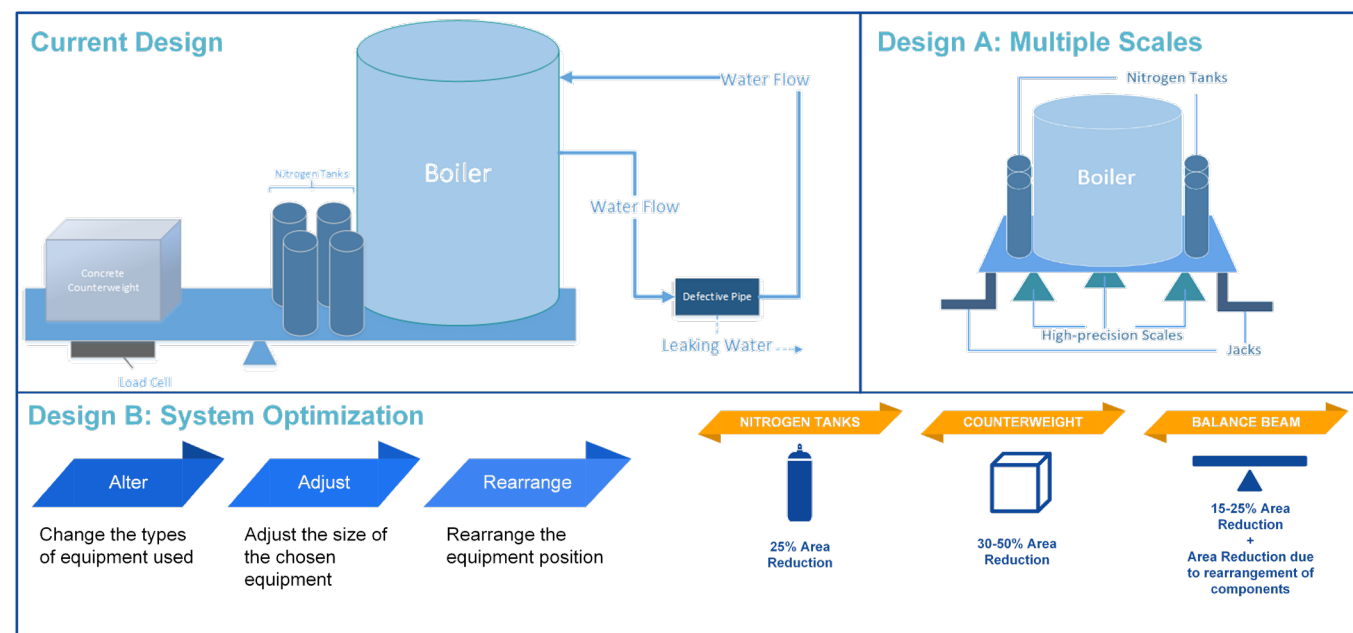
Leak Rate Test Efficiency: Floor Plan Optimization

Client: Kinectrics
Team Members: Medhaj Athilkar, Julia Filiplic, Kyle McFarlane, and Yilun Wang
Supervisor: Murray Thomson

Reducing Footprint and Maintaining Test Validity

Kinectrics, a leader in providing testing and consulting services for the energy industry, requested a redesign of their leak-rate test setup. The leak rate test is used to measure the rate at which water leaks from a defective pipe. The rate is calculated by measuring the change in weight of a boiler that feeds water to the defective pipe. Currently, the setup has an accuracy of ±300 g.

The major drawback of the setup is that it takes up a lot of space. Kinectrics requested for the test setup to be reduced while maintaining or improving the accuracy. The reduced footprint will allow better utilization of the space for other projects or storage for tests whereas the maintained or increased accuracy will ensure nuclear power operators of the reliability of their equipment. Maintaining the safety, validity, and integrity of the test is crucial in ensuring that nuclear power plants are safe to operate and that the communities around these plants are safeguarded.

Two Approaches to Addressing the Problem

Design A - Multi-scale System: This system leverages the latest advances in scale technology. Three high precision scales will be placed uniformly underneath the boiler to measure the weight change. A set of hydraulic jacks will be used to place the boiler on the scales when the test is run. This design eliminates the need for counterweights, improves the accuracy, and greatly reduces the footprint of the test.

Design B - System Optimization: This involves reducing the size of the components, reorganizing the layout, and substituting the components, to reduce footprint. Specifically, improvements to nitrogen tanks, the counterweight material, and the balance beam are proposed. This design won't require new training for employees or operators of the test and it maintains the accuracy of the current test.

Proposed integrated solution

Current system with tube connections
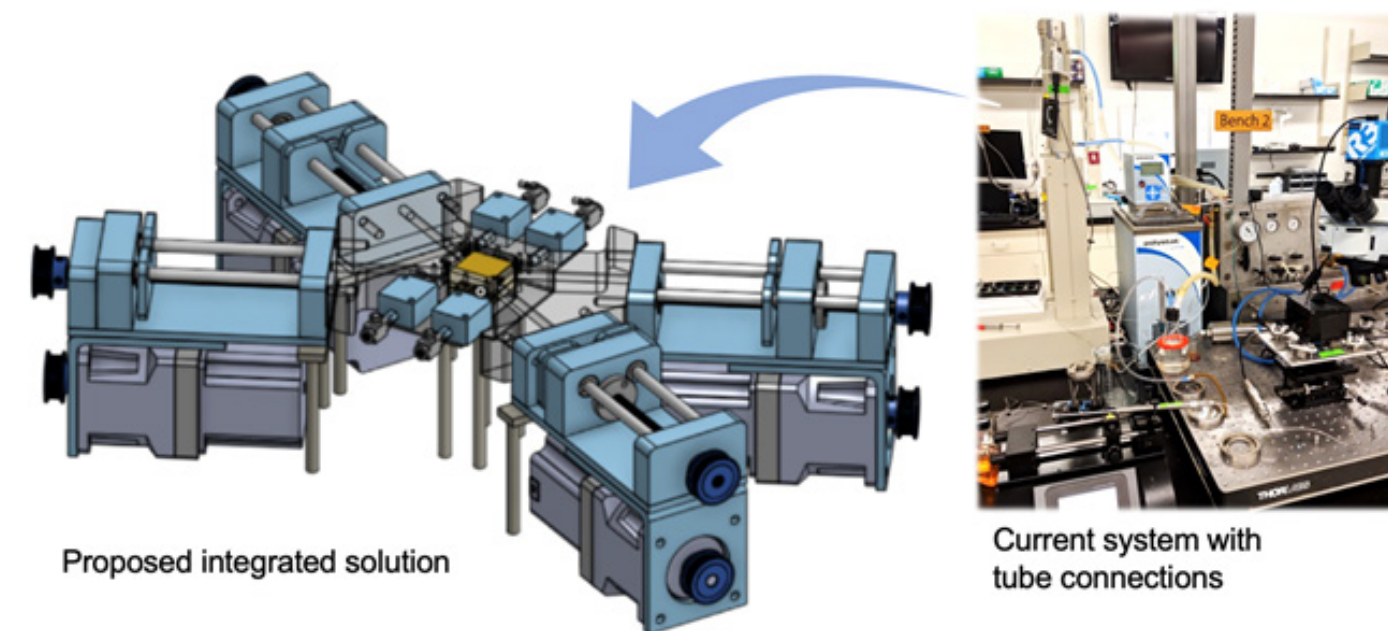
Microfluidics Without the Tubes: Integration of pumps and manifold for on-chip industrial chemical testing

Client: Interface Fluidics Ltd
Team Members: Richard Salas Chavez, Zhanguang Zhang
Supervisor: David Sinton

Doubling profits through innovative microfluidic test setup

Interface Fluidics provides fluid testing services using high-pressure and high-temperature microfluidic chip tests. However, their productivity and profitability are limited by on-chip and off-chip interconnection. The flow control unit currently used by our client includes four massive syringe pumps connected with tubes, which cost more than $120,000 in total. Furthermore, setting up all the tube connections for a test takes around 3 hours. This contributes to a higher cost per test and limits the growth of the whole company.

The objective of this project is to design a low-cost, compact flow control unit without any tube connections. Success in doing so will significantly reduce the cost and time required to conduct fluid analysis with microfluidic chips. Given the great potential of microfluidic technology in biomedical diagnostics, development of such a low-cost flow control unit is of great importance for the diagnosis and treatment of epidemic disease in developing countries.

Integrated module with high-pressure and low flow rate capabilities

This design successfully eliminates tube connections by integrating pumps, manifold and pressure control unit in a single module. Removal of tube connections simplifies setup of the system and minimizes the dead volume in fluid channels. The system can achieve the followings:
- Constant pressure mode (maximum of 200 psi, can upgrade to 10,000 psi)
- Constant flow rate mode (minimum flow rate of 0.01 µL/min)

The design costs less than one thirtieth of the current system. The design will enable Interface Fluidics to carry out more tests per working day, thus increasing their profitability. Commercialization of this design will enable a broader application of microfluidic tests in third-world countries to diagnose and treat epidemic diseases. Also, microfluidic research will be accelerated by enabling experiments to be carried out much faster.

Aerospace
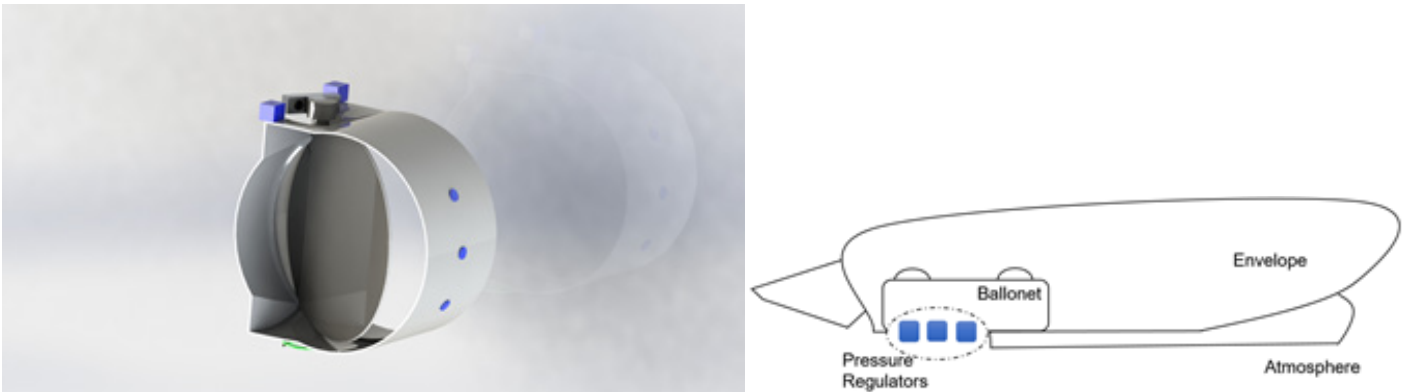
Airship Passive Pressure Regulator

Client: SolarShip Inc.
Team Members: Ahmad Nabi, Haoyu Huang, Yulim Lee, Yuming Zhang
Supervisor: Olivera Kesler

Reducing Mechanical Complexity to Ease Maintenance

SolarShip requires their existing pressure regulation system to be redesigned to incorporate more passive components for their lighter-than-air airships. The complex active components currently being used in the design entail aircraft grounding to perform maintenance on a frequent basis. The proposed valve design is less complex, only exhibits passive failure modes, and reduces the amount of time as well as resources spent by the client on maintenance.

Design Overview

The designed sealing forces are attained through passive magnets implemented directly into the valve body. This novel magnet implementation achieves a more reliable seal and prevents fluid leakage through burping. The passive magnets also provide the force needed to return the valve to a closed position, aiding in sealing. Failure mode data is utilised to create an improved maintenance priority for the client.
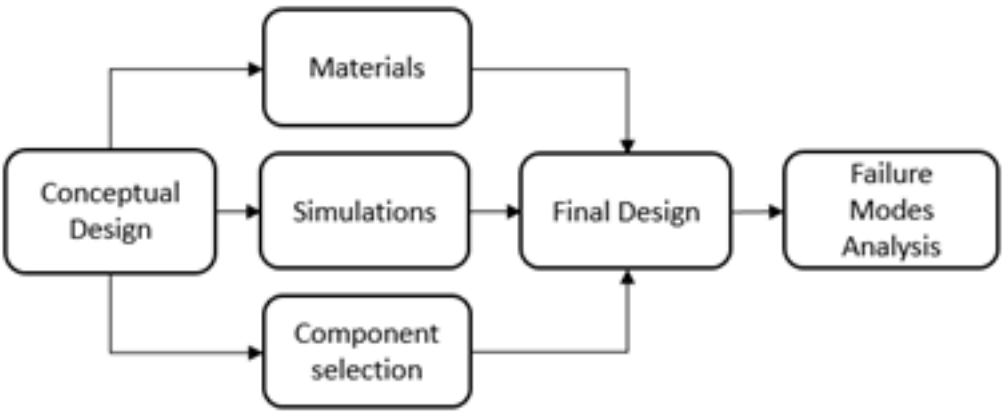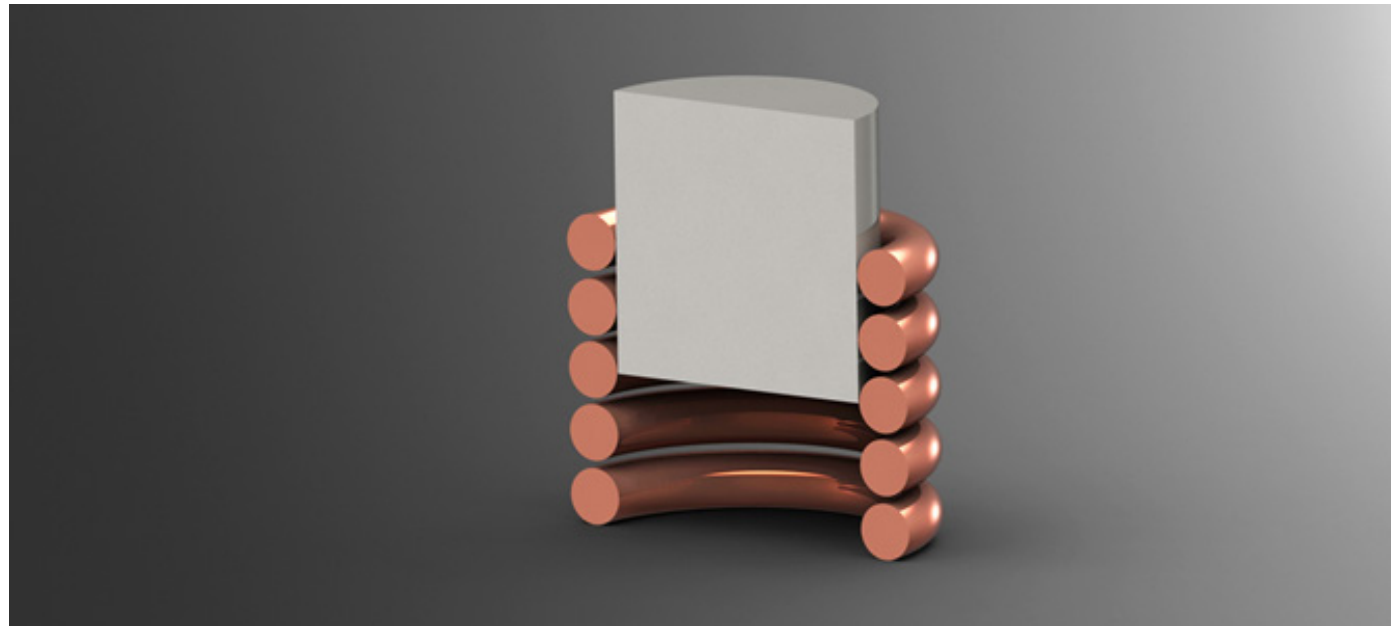
Fluidless Landing Gear Shock Absorber

Client: Safran Landing Systems
Team Members: Raul Akhoundov, Ravi Boparai, Juan Infranco, Linna Wei
Supervisor: Hani Naguib

Fluids in Current Designs Result in Maintenance and Storage Issues

• Seals are required in current fluid-based designs that are known to degrade with time and usage, which can be a source of leakage, and require frequent maintenance.
• The usage of seals also prevents the possibilities of using this type of shock absorber in any "deployable" application which involves a long out-of-service time.
• A redesigned shock absorber would impact scheduled service intervals, minimize unscheduled service occurrences, and generate the possibility of aircraft applications with long out-of-service times, yet possessing the readiness to enter service with minimal to none preliminary maintenance.

Electromagnetic Shock Absorbing as a Fluidless Damping Alternative

• Design serves as a proof of concept for the absorption of landing force and vibrations for a small aircraft by using electromagnetic technology.
• Coils wound tightly around a moving permanent magnet are able to resist the motion of the magnet when AC current is applied.
• Each coil consist of 8,568 copper wire turns, and is controlled independently by a controller (controller not within scope of this project).
• AC current in the coil induces a Lorentz force which acts on the magnet in the center, and only one coil at a time is activated to avoid interference.
• 5 coils, placed 6 cm away from each other, center-to-center, make up a 30 cm stroke.
• The design allows for fully variable damping, as applied by the controller, allowing for different settings for varying landing scenarios.
• Design is aimed at smaller aircrafts and drones.
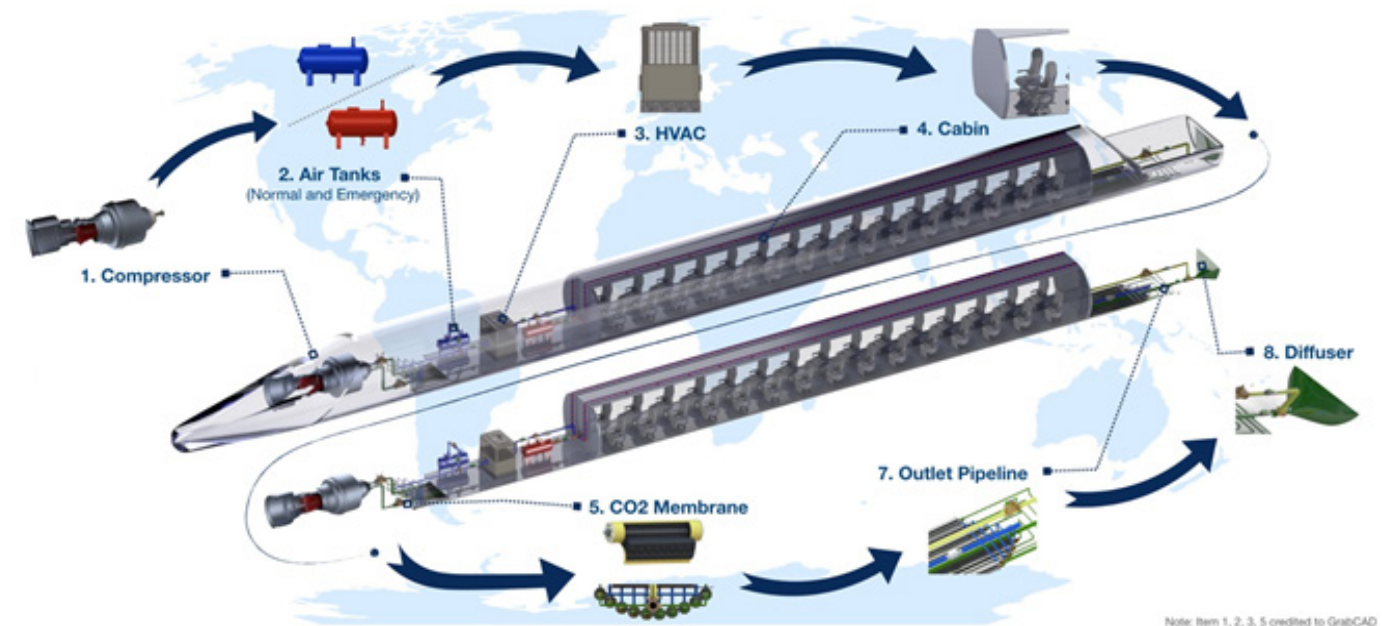
HyperAir - Hyperloop Pod Air Supply System

Client: Advanced Research Laboratory for Multifunctional Lightweight Structures
Team Members: Jingcheng Shan, Hengsheng Yang, Ruihe Zhang, Yakun Zhao
Supervisor: Kamran Behdinan

Supply Air in Vacuum

Traveling through vacuum tubes, Hyperloop provides unparalleled future mobility while posing great challenges to the pod air supply system for the passengers inside. Specifically, these challenges include supplying the pod with air of stable pressure and good quality in vacuum environment, as well as, handling pod air leakage. Successfully verifying the feasibility of this project's will propose an effective air supply solution with the consideration of both normal and emergency scenarios. Furthermore, this project will facilitate the overall development of Hyperloop and bring this futuristic transportation mode closer to the reality, reducing public dependency on traditional, energy-intensive transportations.

Recirculation, CO_2 Removal, Inflatable Sealing Layer

After assessing the characteristics of various air sources under normal condition and reliability of different leakage sealing mechanisms under emergency condition, the final HyperAir design will achieve air supply through pod air recirculation and resolve air leakage emergency with one preciously controlled inflatable layer. The normal operation working process is demonstrated as the flow diagram demonstrated shown above.

Particularly, HyperAir system introduces CO_2 removal membranes while recirculating air within the pod, consequently, maintaining proper air quality under normal operation. Benefited from this mechanism, HyperAir involves no direct air exchange between pod and outside vacuum, leaving minimal effort of stabilizing cabin pressure while providing adequate ventilation rate. Moreover, the designed control system monitors the pod interior environment on real-time basis and will activate emergency protocol if any leakage is detected. Particularly, with the capability of leakage localization, one adjacent inflatable sealing layer will then be deployed to block the leakage. Meanwhile, the pod will be re-pressurized by an emergency O_2 supply tank.

Ultimately, one scaled-down prototype is constructed to validate the performance of HyperAir control system with respect to ventilation rate regulation, leakage detection and emergency protocol execution. The testing results is evaluated and then utilized to further prove the reliability of HyperAir system.
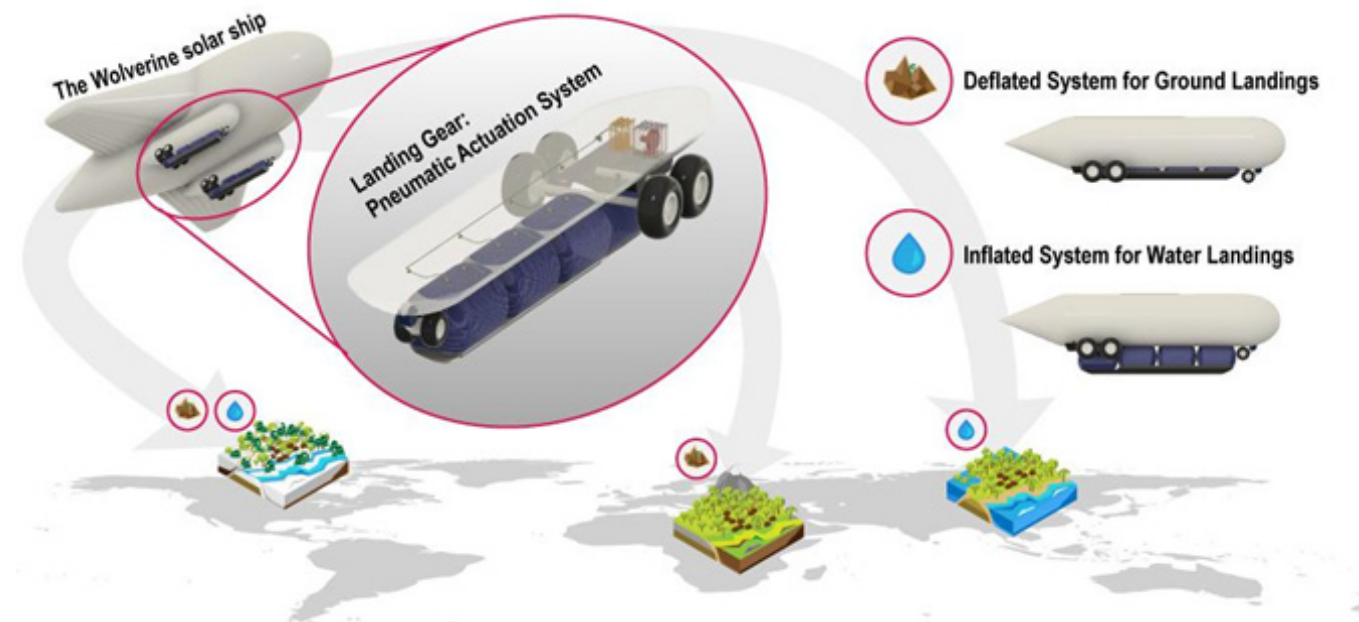
Portum Tutum, An Amphibious Landing Gear Design for Hybrid Airship

Client: Solar Ship Inc.
Team Members: Amier Faudzi, Christine Bui, Romaissa Allalou, Sabrina Lokman
Supervisor: Olivera Kesler

Expanding frontiers

• Remote areas such as landlocked African countries and lake laden Canadian North have meager ground transport infrastructure and an insufficient number of airstrips to maintain healthy trade networks of vital goods.
• Solarship Inc. tackles this problem by designing and building solar-powered hybrid airship termed solarships to deliver essential cargo to remote areas. They achieve this by having short takeoff and landing (STOL) capabilities, and a high payload capacity.
• To better address this market, they are seeking a conceptual design for a landing gear system that would add water landing capabilities to their solarships.
• The objective of this project is to develop a landing gear system that enables solarships to transition between ground and water landings as well as to support its operations on both land and water without sacrificing payload capacity and flight range.

Water landing demystified

• The proposed design, the Portum Tutum, uses an electronically controlled pneumatic system to inflate and deflate a series of air bladders past a set of rigid, fixed wheels.
• A rigorous idea generation and preliminary prototyping phase generated over 30 ideas that identified pneumatic actuation as the most feasible design. Preliminary design validation was assessed using load simulations and CAD modeling.
• In order to meet the tight design specifications of solar ships, component geometry and layout (i.e. the bladder geometry) were optimized using finite element analysis (FEA) and attachment point shear analysis.
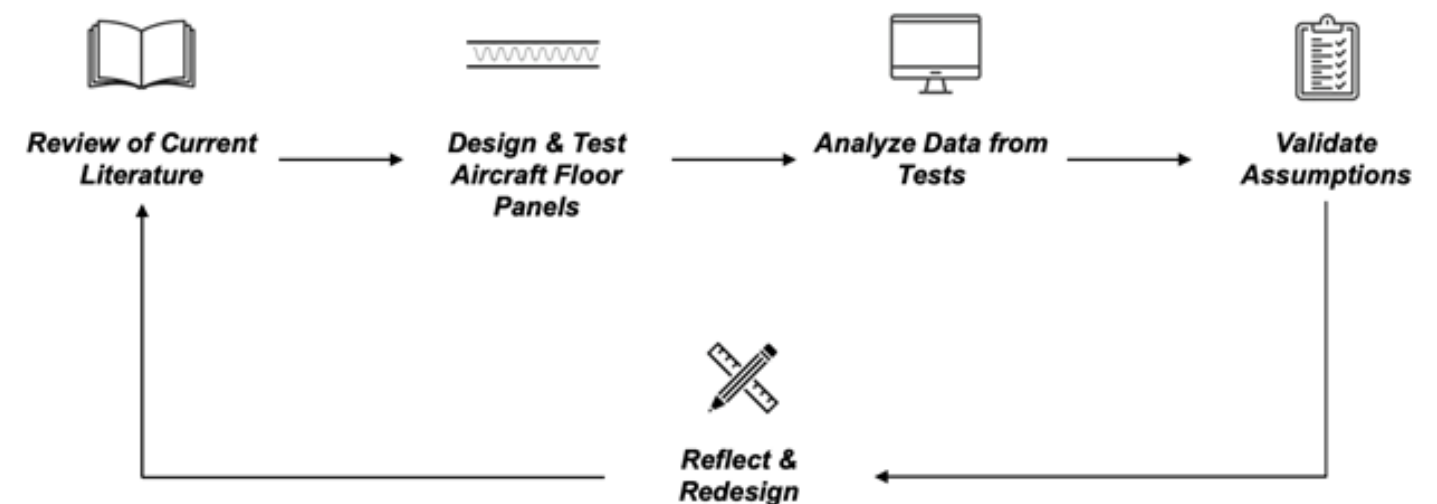
Python Library to Predict Failure Modes in Aircraft Floor Panels

Client: Comtek Advanced Structures
Team Members: Jakub Targosinski, Julian Nappert, Philipp Haas, Robert Welch
Supervisor: Jan K. Spelt

Reducing Computational Cost of Aircraft Floor Panel Design

Comtek Advanced Structures (or simply Comtek) is a company which designs and fabricates various structural components for large aircraft manufacturers. One of their product lines include sandwich floor panels, which feature in multiple commercial passenger and business planes. In an effort to increase passenger plane fuel efficiency and payload, the aerospace industry emphasises strong, lightweight designs for all aircraft components. This has created a need to reduce overall weight and thickness of the current floor panel designs which has increased the likelihood of uncommon failure modes.

Although existing Finite Element Analysis (FEA) programs are available for use, they are computationally expensive to use, and do not allow for easy implementation of multi-parameter optimization. Therefore, analytical models are preferred for early stage optimization as they provide reasonably accurate solutions at a lower computational cost. The capstone team's objective is to design a Python program which incorporates and predicts the relevant failure modes using analytical methods. The final design will allow Comtek to quickly and analytically predict the strength and mode under which any potential new floor panel designs will fail. This will ensure that future designs meet the customer strength requirements and ultimately allow aerospace companies to produce safer and more fuel-efficient aircrafts.

Solution for Aircraft Floor Panel Design

The team provided a Python library which determines the failure mode and load using material properties and panel geometry for the relevant failure modes: facesheet yielding due to tension and compression, core shear, intracell dimpling, and facesheet wrinkling. This was accomplished by performing an extensive literature review for the aforementioned failure modes and implementing the analytical models into the Python library. Sandwich panels with characteristics associated with each failure mode were then designed, fabricated, and mechanically tested to validate the analytical models.

Cabin environment control system

Mass flow test screen

Diagram of the test cell components

Semi-Automated Testing Duct Cell

Client: Comtek Advanced Structures
Team Members: Roy Saade, (Vincent) Po Chou, Akash Chauhan, Omar Tannir
Supervisor: Javad Mostaghimi

Client Need & Impact

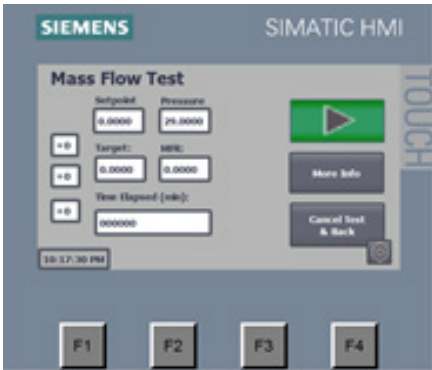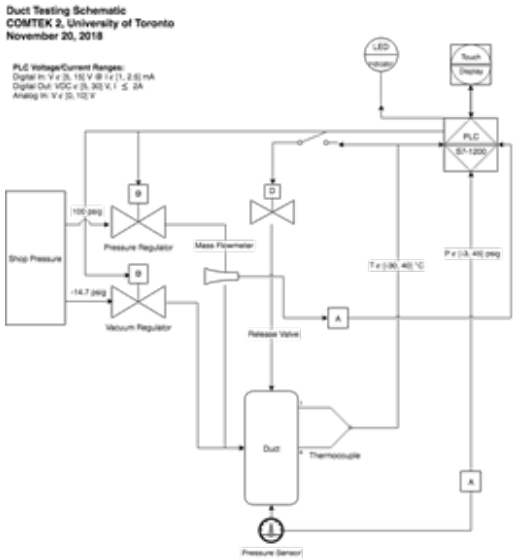Comtek wants to start producing ducts for commercial aircrafts. A reliable testing procedure is needed to ensure the quality and reliability of their products. Our semi-automated test cell will be used as a cornerstone for Comteks' testing procedure which will allow them to venture into the duct production market. The ability to test ducts for leakages will allow Comtek to improve their products and lead to more efficient Environment Control Systems of commercial aircrafts reducing fuel consumption and providing better comfort and safety for the passengers on board.

Overview of design/key results

The test cell is divided into two major parts: the testing apparatus, and the automation process/interface. The testing apparatus uses pressure regulators to reduce the shop pressure to the required duct pressure. After achieving steady state, a mass flow meter measures the leakage rate and a pressure sensor measures the pressure at the duct.

Automation is achieved using code we developed and runs on a circuit based around a Programable Logic Controller (PLC). We reduced the tasks required by the operator to: installing the duct, inputting the test conditions and initiating the test. The PLC monitors the system and stops the test in case of error or safety hazard. Otherwise, the measurements are conducted and presented to the operator as a pass or fail with an explanation in case of a failed test. Our solution is about 20% more time efficient than a complete manual test and it ensures the repeatability, dependability of the test procedure. Also, using a PLC monitor the test allows the user to analyze the test results in case of a failure.

Going forward, Comtek will add a duct scanning system to improve automation. Also, Comtek would need to improve our design by developing special end caps that we designed that would allow them to save more time while testing different type of ducts.

Shimmy Damper Test Device Design

Client: Advanced Research Lab for Multifunctional Lightweight Structure (ARL-MLS)
Team Members: Jia Cheng Fu, Qi Xiu Wu, Zhiyang Liu
Supervisor: Kamran Behdinan

Culprit of a Terrible Flight Experience

Shimmy is a self-induced torsional and lateral oscillation on landing gear during ground operation. It causes impairment of pilot's control of the aircraft, passenger discomfort and catastrophic landing gear failure. Shimmy dampers are typically installed separately on the landing gears to absorb harmful kinetic energy from shimmy. ARL-MLS is developing a new shimmy damper that will be integrated into the nose landing gear structure to counter the shimmy vibration. As a result, there is a need for a shimmy damper test device to evaluate the performance of the damper.

Beneficial Impact

The test device can help the researchers/engineers on improving the dampers which can benefit relevant individuals and organizations in several ways:
- Improves aviation safety by lowering catastrophic landing gear failure rate
- Creates better flight experience for flight crew and passengers due to higher stability of airplane
- Yields higher profit margin for airlines by reducing landing gear repairing and maintenance costs
- Passengers will enjoy lower airfare due to cost reduction.

An Effective Solution for Damper Evaluation

The design was generated by carefully and repeatedly reviewing the design requirements and properly selecting mechanical and electrical components. The completed design is fully automated by a Siemens PLC which controls a 7.5kW Yaskawa geared servo motor to produce rotational oscillation similar to shimmy and the motion is transmitted to the sample dampers. The linear variable differential transducers (LVDT) are mounted parallel to the dampers which measures the displacement data of damper pistons. The data will be processed and stored in the PLC for further analysis. By evaluating the performances of different dampers, ARL-MLS can identify the potential improvements for the damper and further increase its efficiency.
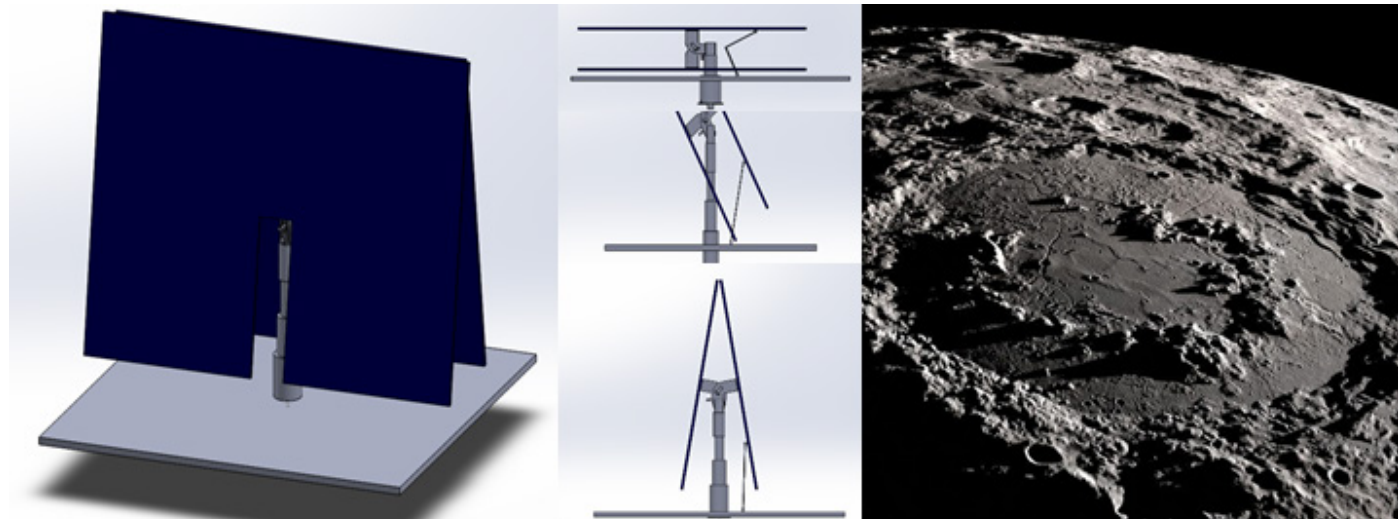
Images (left to right): Mast Configuration, deployment of the Mast Configuration, Schrodinger's Basin (mission location).

Solar Array Development for Lunar Surface Mobility Rover

Client: MacDonald, Dettwiler and Associates Inc.
Team Members: Kevin Nguyen, Nabil Hassan, David Pecile & Nicholas Petrelli
Supervisor: Yu Sun

Problem Statement & Impact

The client, MDA a Canadian space-technology company, has been tasked with the design of the Lunar Surface Mobility (LSM) Precursor to Human And Science Rover (PHASR). PHASR must mitigate the effects of the harsh lunar environment including lunar dust particles (regolith) while harvesting its own energy using solar panels. MDA requires a trade study comparing two solar array configuration types: a sun tracking and stationary configuration. The study shall determine the final optimal design that will be fully designed for the client. This problem directly contributes to Human Enhanced Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES), a project focused on implementing a prolonged human presence on the moon.

Engineering Analysis/Design

A matlab code was developed that simulated the sun's trajectory to derive the direct solar irradiance to determine the optimal solar panel size and orientation based on mission requirements and locations. A full State of the Art Survey highlights space grade materials, solar cells & arrays, and dust guard technologies to ensure that this mission will directly benefit future space endeavors. The stationary design scored highly on objective weighting that was based heavily on durability, simplicity and energy efficiency. The final selected design, the Mast Configuration, has two stationary solar panels deployed at 10° from the vertical. This design is very simple to limit failure modes, contains minimal moving parts, and meets the constraint for launch configuration volume envelope. The system deploys with a telescoping boom that raises the shaft, while a series of linkage mechanisms moves the solar arrays to the correct angle.

Automotive and Transportation

Existing Vehicle: Shadow

New Aerobody: Jaguar

Improved Energy Efficiency
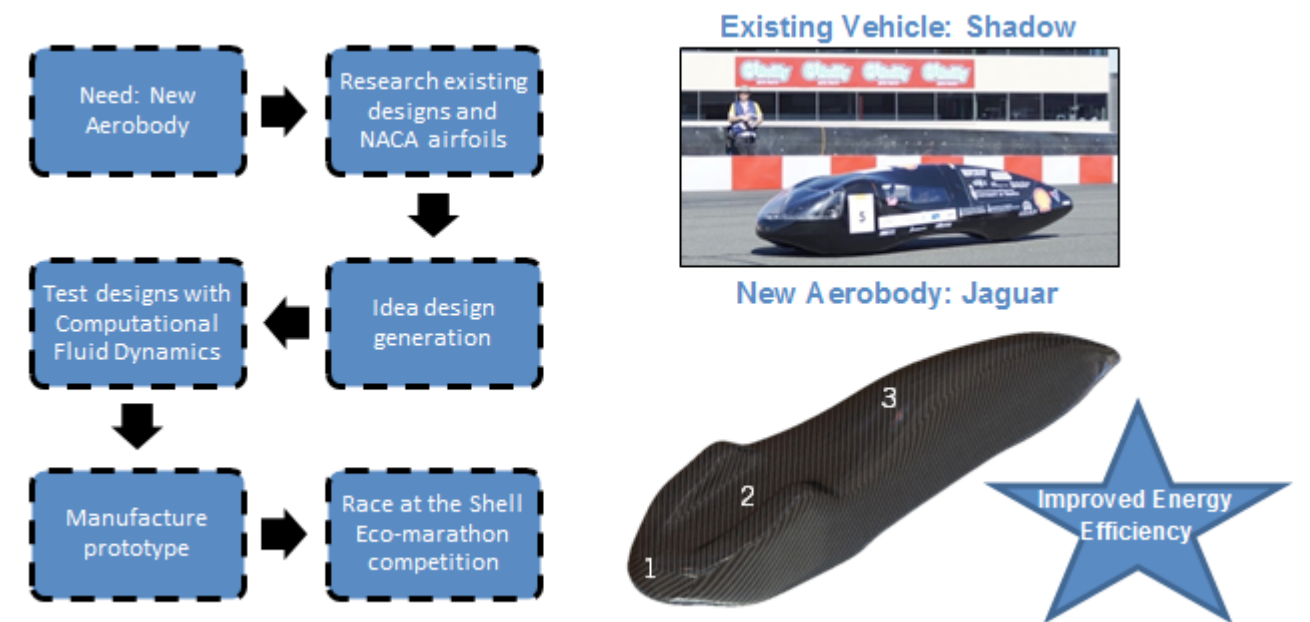
Design of Prototype Vehicle Aerobody

Client: Kristine Confalone, Carbon Cutting Racers Design Team
Team Members: Callum Bartlett, Melissa Fung, Natalie Khoury, and Janina Taberna
Supervisor: Markus Bussmann

New Aerobody Design Plan

The Carbon Cutting Racers Design Team (CCR) designs, builds, and races ultra-efficient internal combustion vehicles that showcase energy efficient technology in the automotive industry. They compete annually in the Prototype class of the Shell Eco-marathon Americas (SEM) competition to see which vehicle can travel the furthest using the least amount of fuel. This capstone team's scope is to deliver an aerobody design for CCR to manufacture and race at the SEM competition.

FUNCTION
- Internally house the mechanical systems, electrical systems, and driver

OBJECTIVES (compared to existing vehicle, Shadow)
- Low drag area (< 0.0561 m2)
- Less overall size (length < 2,743.2 mm)
- Low aerobody weight (< 21 kg)
- Affordable plug cost (< 5,000 CAD)

CONSTRAINTS
- Conform to the SEM competition rules

Energy Efficiency Impact

Growing global awareness of the impacts of climate change has driven a focus on the development of new technologies to increase energy efficiency and decrease global emissions. The team designed an innovative aerobody that considered these technologies within the Jaguar design. Based on the computational fluid dynamics and the wind tunnel simulations, Jaguar is expected to excel and surpass the existing vehicle's fuel efficiency. Ultimately, the aerobody design is critical for the client's future success at the SEM competition and to further the development of energy efficient technology.

Jaguar Design

The final aerobody design, named Jaguar, is selected for its creative design features and its objective performance.
- Recess between the front two wheels (2): contributes to lower drag, improved manufacturability, and better visibility
- Upright driving position: gives driver more leverage over the steering wheel and is more ergonomic. The feet are located at (1) and the head is at (3).
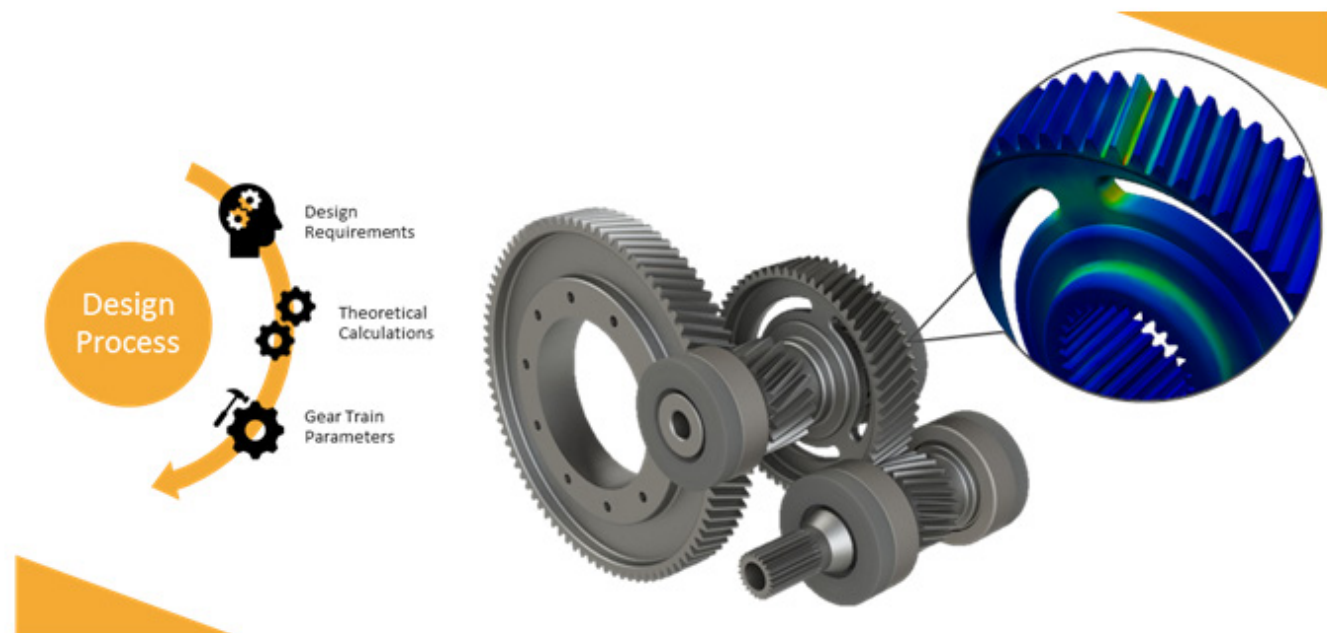
Electric Vehicle Gearbox Redesign

Client: Dana Incorporated - Shanghai
Team Members: Abhishek Risbud, Feras Zeineddine, Olasope Edwards, & Sherif Refaie
Collaborators: Shanghai Jiao Tong University (SJTU)
Supervisor: Kamran Behdinan

Background: Electric Vehicles & Climate Change

In recent years, an increase in public awareness of greenhouse gas emissions and their negative environmental consequences has resulted in increased consumer demand. With more efficient electric vehicles, the human impact on the environment can be significantly reduced. Thus, there is a global developmental push for efficient electric vehicles that can outperform and compete with the convenience and practicality of traditional fossil fuel vehicles.

Challenge: Improving Electric Vehicle Efficiency

Dana Inc. is a global transmission and drivetrain automotive-supplier. Dana currently offers its lightweight Spicer® Gearbox for passenger electric vehicle manufacturers. Dana has reached out to the teams at SJTU and University of Toronto (UofT) to collaborate on redesigning the gearbox. The aim is to reduce the overall weight of the gearbox by 8-20%, while maintaining key performance, thereby improving the overall efficiency of the manufacturers' vehicles.

Solution: Gearbox Weight Reduction

Both teams collaborated to narrow down the considerable scope of the gearbox, with SJTU focusing on the housing and UofT on the gearing and shafts. The UofT team employed a methodological comprehensive design approach. First, distinctive gear train concepts were generated and thoroughly compared, with one final concept being chosen. The final concept consisted of a two-stage helical gear train, that transferred the energy of the electric motor to the wheels at Dana's specified speed ratio of 10.86:1. The team further conducted extensive theoretical and simulated stress analyses on the design to verify functionality, strength requirements, and ensure industry standards were met.

A full-scale 3D-printed prototype of the slightly modified final design was constructed, in lieu of a fully manufactured design due to budget considerations. The prototype verified the form, fit, and function of the final design.

HiHo Mobility's Smart Automated Locker Transport System

Client: Tim Lichti, HiHo Mobility
Team Members: Chokpisit Kasemphaibulsuk, Jiayu Hu, Konica Baveja, Nirwan Pradhan
Supervisor: Xinyu Liu

Enabling Maximum Usage of Work-Fleet Vehicles

The initial capital cost of purchasing work-fleet vehicles are high, especially when they are only being used 5% of the time. If tools were stored in storage lockers and were made easy to transport, this inefficiency could be drastically reduced. If the number of work fleet vehicles could be reduced and replaced with electric vehicles, there would be less traffic and parking congestion, resulting in less pollution. The companies using the services would also save money required to own and maintain their fleet as well as storage space to keep the vehicles in. A method for transporting these lockers to work sites would be extremely beneficial in this aspect.

Developing the Locker Transport System and the Challenges Faced
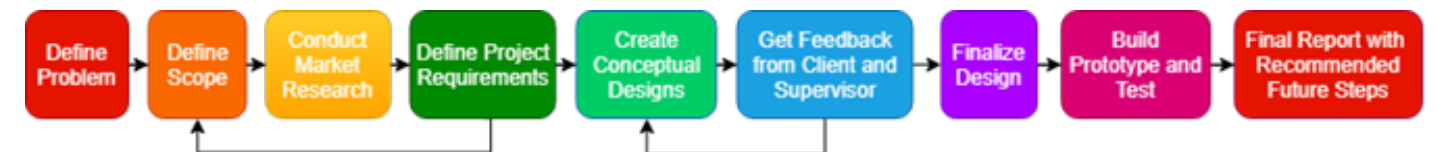
The initial project scope was to design a mechanism to remove the lockers from backseats of SUVs and place them inside storage shelves. The team defined the functions, objectives, and constraints of the design and conducted market research on existing mechanisms with similar applications. As the team entered the design phase, the project scope was redefined to be compatible with a different style of vehicle and storage space. The team then began brainstorming ideas for conceptual designs for the new project scope, breaking the design down into several subsystems. Multiple alternative designs of each subsystem were considered, and the best option was chosen by analyzing the advantages and disadvantages of each component.

In the final stage, the team built and tested a prototype which meets the functions, objectives, and constraints that were defined earlier.

[1]"Ice Rally on TESLA | Activity Item | Travel Finland | Lapland | Taxari.com", *Travel Finland | Lapland | Taxari.com*, 2019. [Online]. Available: https://taxari.com/activities/rally-car-competition/. [Accessed: 19- Mar- 2019].

Making Electric Vehicles Feasible in Extreme Cold

Client: Thermolynx Ltd.
Team Members: Louise Xie, Shiva Ghasemi, Sana Sadeh, Kamal Mukhalalaty, Aminur Khan
Supervisor: Sanjeev Chandra

The Challenge Electric Vehicle Automakers Face

Vehicles with internal combustion engines make use of engine exhaust heat to assist heating the passenger cabin during cold conditions. However, electric vehicles (EVs) do not generate exhaust heat. This makes it challenging to heat EV cabins in cold conditions using their existing HVAC system. To compensate, many EVs use their batteries to power coolant heating units. Coolant heating units on the market today use Positive Thermal Coefficient (PTC) resistive heating elements which are slow and inefficient. The limitations in vehicle range associated with the high energy consumption of coolant heating units are a challenge automakers are facing to overcome. Our client, Thermolynx Ltd, is developing a coolant heating unit by utilizing their thermal spraying technology. The team aims to develop a conceptual design for the unit with the goal of improving the heat transfer efficiency.

What The Team Achieved

The team utilized the engineering design process and benchmarking techniques to generate candidate designs. Design for manufacturing and assembly considerations were integrated into each design in addition to ensuring that each candidate adhered to automotive industry standards. Analytical assessment of each candidate was performed by constructing models to determine heat transfer performance. The team ranked each candidate by considering the extent to which it met functional requirements and objectives. The highest ranked candidate was selected as the proposed design.

The proposed design's performance was validated and further analyzed using ANSYS simulation software. The yielded results facilitated further design optimization to ensure that a 94% heat transfer efficiency could be achieved.
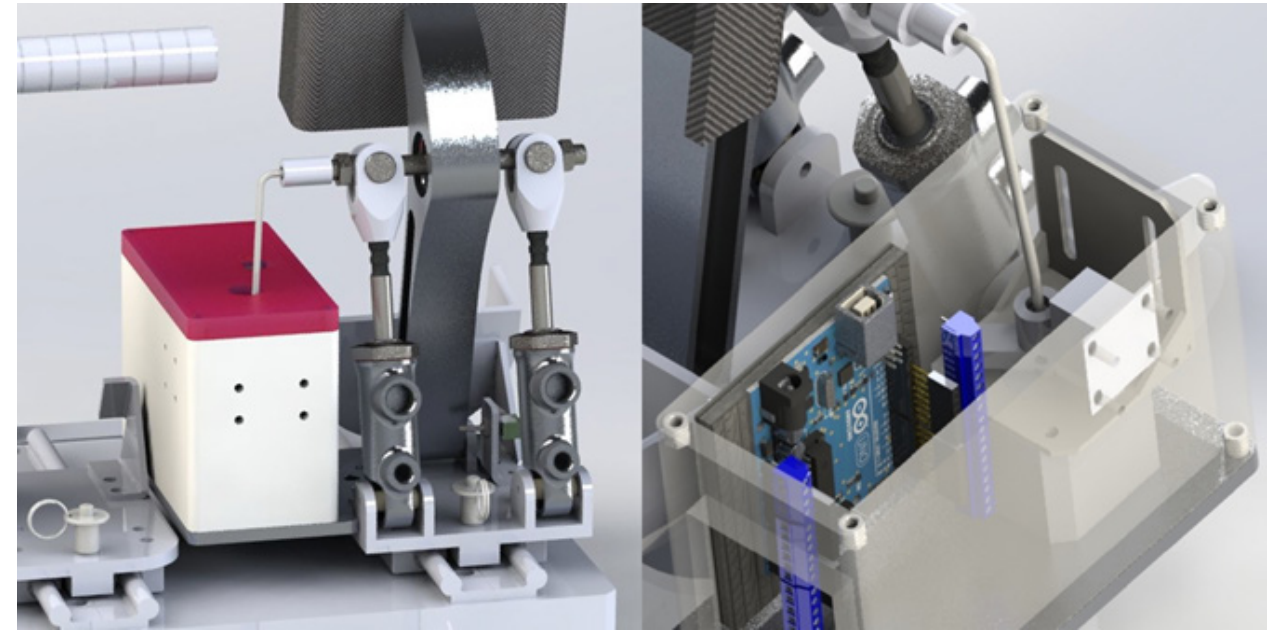

Providing Digital Control for Brake Bias Adjustment

Client: University of Toronto FSAE
Team Members: Alan Fernandes, Paanugoban Kugathasan, Atif Iqbal, Linshaojie Pu
Supervisor: Anthony N. Sinclair

Reimagining a Competitive Edge by Employing Bias Bar Adjustments in Races

The University of Toronto's FSAE team requires a brake bias adjustment design which can be easily operated during a race. The current method of bias bar adjustment is an inconvenient process, requiring removal of the nose cone and manually changing the bias bar's jam nuts. The bias setting is difficult to accurately replicate and cannot be performed during a race, remaining at one constant setting. The bias bar is responsible for adjusting the braking ratio between the front and rear brakes. Modifying this ratio offers the driver increased maneuverability and flexibility on the race track, allowing for faster lap times. The primary objectives of the design were quick adjustment, accurate bias control and minimizing space occupied. With an easily accessible method to adjusting this ratio during races, the FSAE team will have a significant competitive edge.

Mechatronics Approach to Delivering High Accuracy, Repeatability and Speed in Brake Adjustments

The Arduino is at the heart of the design, connecting user inputs to the adjustment of the bias bar. Push-buttons will send signals to a motor to rotate in the direction of intended bias. A locking solenoid which prevents free spin of the motor shaft will retract and allow the motor to rotate a steel cable, which will adjust the bias bar in increments of 5%. Simultaneously, an OLED screen will provide real time feedback of the current bias setting to the driver. A mechatronics approach combining the advantages of mechanical and electrical systems was employed to solve the accessibility and accuracy requirements, while providing the motor detent fail-safe. Through CAD modelling, microcontroller programming and prototyping, a final design was proposed. The adjustment of the brake bias can now be easily operated by the driver during the race with precision. With correct strategic planning, the new brake bias adjustment system can result in improved track times and bringing the team one step closer to the podium.
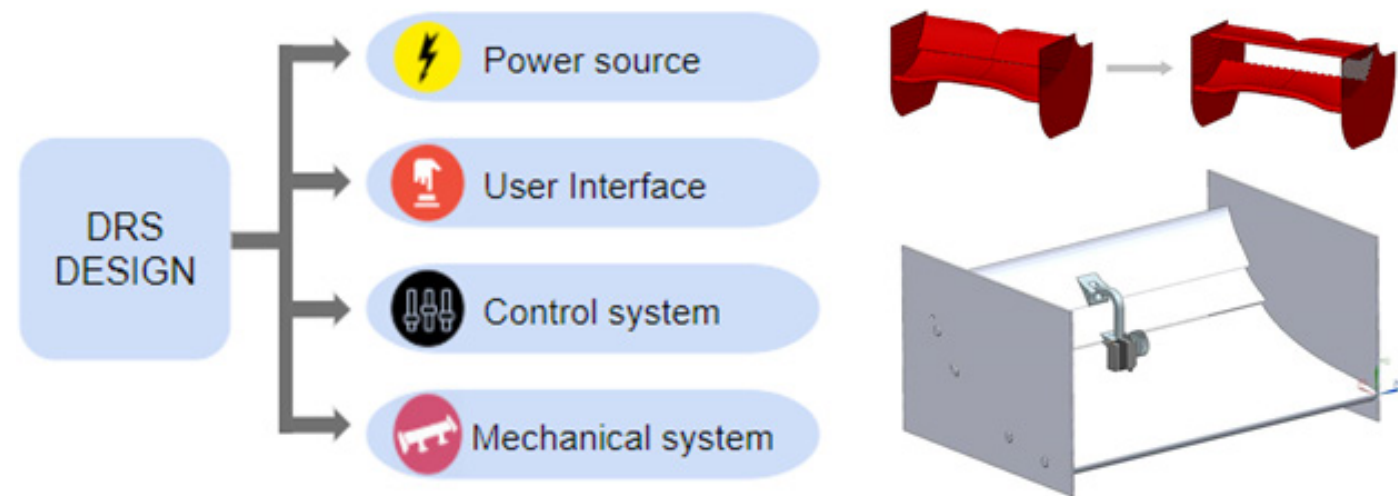
Why a Drag Reduction System is the Solution to Overtaking?

Client: Camilo Escobar
Team Members: Adrian Cheung, Joshua Dzakah, Kyle Mccarroll, Likang Chen
Supervisor: Edmond Young

Client's Need

In a competition where the slightest lead matters, auto racing teams are making their cars more aerodynamic to give them an edge over their competitors. The University of Toronto Formula Racing Team, seeks to design a drag reduction system (DRS) for their 2019 Formula SAE (FSAE) race car. The current 2018 FSAE car requires the two adjustable flaps to be manually set to a desired position when the car is fully stopped. Once the race begins, the driver has no other method of controlling the position of the wings and this evidently leads to a clear disadvantage in racing situations.

Design Overview and Key Features

The DRS is an automatic control system aimed at reducing aerodynamic drag in order to adjust drag and normal force to optimize performance. The design is powered by an external voltage source for the motor. The motor is used to rotate the spoilers along its pivot points. Code is implemented on the existing engine control system to govern motor movement. The driver can activate the system by using the switches that will installed on his steering wheel. The result of our design is aimed to have a 4 to 5 kph advantage. Our product is decent as it has three distinctive features:
- Hands-free Control: The spoiler system automatically adjusts the spoiler.
- Lightweight: The DRS accounts for only 1% of the car's weight at approximately 4 pounds.
- Affordability: By using an affordable motor and 3D printed parts, the cost estimation is at $205.

The Impact

Short term success will be dictated by the DRS's performance at the 2019 Michigan race. The long-term goal is to create a strategic alliance partnership with the Formula 1 company to market towards low-end race cars companies as our primary consumers. Our product is aimed for car owners with the desire of a functional self-automation technology for their spoiler without paying the premium price.

Energy and Environment

An Alternative Energy Saving Solution: Heat Recovery System for Conventional Oven

Client: G. CINELLI ESPERIA CORPORATION
Team Members: Suchen Wang, Xuecheng Yuan, Jing Du, Liwen Zhou
Supervisor: Jordan Bouchard & Sanjeev Chandra

Improving efficiency without major changes

G. CINELLI ESPERIA is a family owned corporation that design and manufacture bakery machinery over 40 years. Their newest bakery oven has been developed in the last 3 years with UT capstone teams; the prototype has been finished and under testing. We, as the 4th design team, was given the tasks of supporting the tests and designing a method to continuously improve the total efficiency without major changes on the prototype.

One major source of energy loss of the bakery machine is from the exhaust gas. The original total efficiency, which was 85.6% can be improved if the heat of the exhaust gas can be reused. Since, we cannot modify the prototype itself, a heat recovery unit outside the prototype is considered. We designed a fin-based gas-to-water heat exchanger which is located onto the exhaust pipe to extract the wasted heat, then transfer the heat by heating up water for other usages, such as heating for the factory and snow melting. With the add on heat exchanger, total efficiency increases by 4.6% with a 3-year payback period.

Impact

The idea of making improvements by placing accessory devices can be applied to all the mechanical systems. It makes it easier and cheaper to apply improvements and new technologies without major changes to the original design.

G. Cinelli ESPERIA prototype oven had increased this efficiency from 85.6% to 90.2% by installing our new designed accessory device (heat exchanger). In addition, the collected heat can be used for another project, such as maintaining the temperature for drinkable hot water which originally cost electrical or other energy sources. This project makes an effort to save energy which results in reducing the greenhouse gas emission. It contributes on preventing global warming and gains a positive impact on the environment.
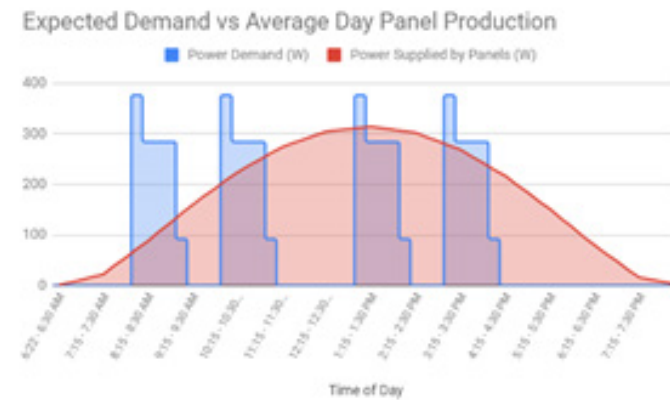
Empowering Students Through Sustainable Off-grid PV Power

Client: Paul Leitch, Director of Sustainability - University of Toronto Facilities and Services
Team Members: Parham Chinikar, Marawan Gamal, Liam Keller, Katherine Pryszlak
Supervisor: David Sinton

Bringing Solar Power to Gull Lake Camp

Gull lake is a site near Minden Ontario that is owned and operated by the University of Toronto. This site is used during the summer months by students attending a land surveying camp located on the premises. The team was tasked with developing and optimizing an off-grid PV system to offer sustainable, self-maintained and relatively inexpensive power generation on a remote site at the camp.

The main objective for this project was to develop a PV system that provides enough power for students working at the site, is maintenance free, is easy to use, and can be expanded in the future if required.

From Concept to Realization

The available solar power and the estimated power usage by students at the Gull Lake Camp was calculated to provide a basis for system design (Figure 1). By taking a safety factor of 2 into account, we designed a system for a maximum electrical consumption of 2.5 kWh and electrical demand of 750 W. To meet this demand, we used three 24V, 285W ground mounted PV panels, four 6V, 415AH AGM batteries along with a MPPT charge controller and a pure sine inverter (Figure 2). The system provides electricity to multiple outlets as well as time and motion activated lights and fans. In addition to the site specific system, we also provided the client with a novel electrical line diagram that could potentially be used for other implementations.

Impact

By providing electricity at one of the sites in Gull Lake Camp starting this summer, we will enable the visiting civil students to have the freedom of using their electronics while working remotely. The flexibility built into the design will allow for future expansions at the location as well as implementation of other similar off-grid PV solutions elsewhere by the client.

Extending the Growing Season of Nunavut Greenhouse

Client: Green Iglu/Benjamin Canning
Team Members: Bilal Khan, Huzaifa Malik, Lucas Temor, Yu Liu
Supervisor: Amy Bilton

Agriculture in a Subzero Environment

In many areas of Canada's northern territories both traditional agricultural methods and importing produce are extremely difficult. Consequently, the cost of fresh food in these areas can be up to four times more expensive than the average Canadian. Greenhouses like the one started by Green Iglu in Naujaat, Nunavut (image, left) can easily allow communities to have access to produce for the warmer half of the year. Throughout the region's harsh winter season, however, temperatures average around -27°C making it a challenge to sustain an environment suitable for plant growth in the greenhouse. Green Iglu has requested a method of maintaining growing conditions inside of Naujaat's community greenhouse. Extending the greenhouse's growing season throughout the winter could ensure the community has access to fresh produce year-round.

Optimizing Thermal Performance

Four improvements were designed by the team to optimize the greenhouse for winter growing. (i) As a heat supply the team is recommending a perimeter heating system (image, bottom right). This will allow heat to be evenly distributed along the entire perimeter of the dome ensuring a uniform temperature distribution. (ii) The greenhouse uses six fans placed along its perimeter to assists with air circulation. It was found, however, that energy could be saved while achieving the same effect by using four fans that are controlled based on environmental feedback. (iii) It was then estimated that the use of insulation may result in 75% less heat loss from the greenhouse walls meaning there would be less demand on the heating system. As it is not needed in the warmer months, a unique "curtain" design (image, top right) is suggested which will allow for the insulation be easily pulled over its target areas when it is needed during the winter. (iv) Finally, it is suggested that an air barrier (image, center right) be installed above the main entrance in order to reduce heat loss when the door is opened. This device uses a laminar stream of air to create a 90% thermally efficient barrier between the inner and outer climate zones. It is believed that when working together, these systems will be able to maintain growing temperatures in the greenhouse throughout the winter.
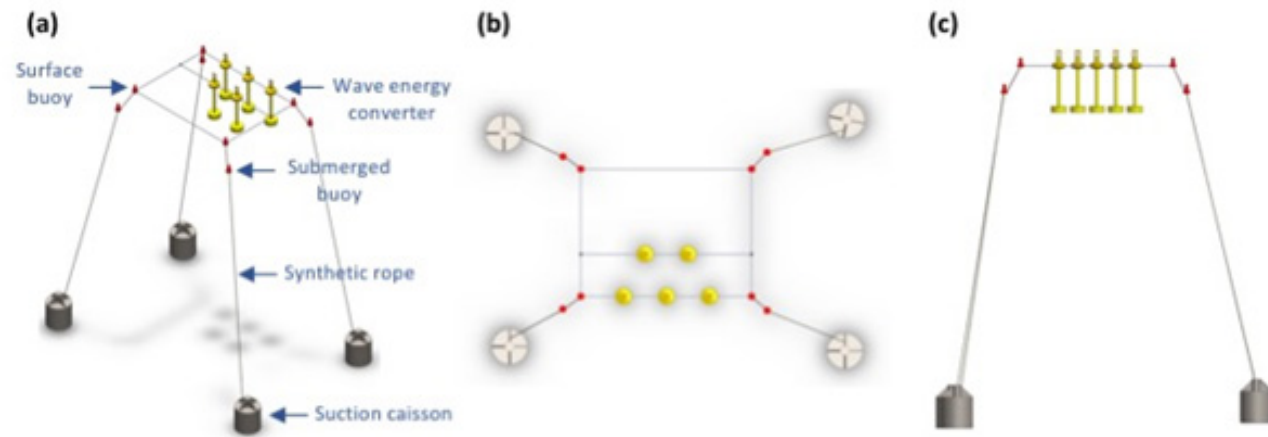
Figure 1: *Tensioned taut leg mooring system design for array of wave energy converters ("WEC"). Each of the four buoys that act as the corners of the WEC array is attached to a submerged buoy. Each submerged buoy is in turn tethered to a suction anchor attached to the ocean floor. The views shown above are (a) isometric, (b) aerial and (c) side.*

Improving Economic Viability of Wave Energy via Anchoring System

Client: WaveGen Techonologies Inc.
Team Members: Gurtej Bhasin, Alexander Dowling, Katherine Kocur, Kyle LeVoguer
Supervisor: Pierre Sullivan

Client Need & Impact—Tackling the economic feasibility of wave energy through array anchoring

In order to address climate change, there is a global need for increased use of renewable energy. Harvesting wave energy has proven to be an engineering and economic challenge, with almost all wave energy projects still at pre-commercial stage.

In order to overcome this challenge, WaveGen Technologies Inc. ("WaveGen") has optimized the placement of wave energy converters ("WECs") into a dynamic array that can be used to maximise the harnessing of constructive wave interreference energy. WaveGen approached the capstone team to design an anchoring system for the array, which is to be located off the coast of Nova Scotia.

Overview of design/key results—Decreasing cost of wave energy through tensioned taut leg mooring

The team decided to design a tensioned taut leg mooring system (see figure 1) because it is the cheapest and least complex option that is feasible at the depth of the implementation environment. Key details of the design are as follows:

- The four corners of array are tensioned by polyester synthetic ropes attached to suction caissons
- Submerged buoys provide additional stability to the system by creating extra buoyancy forces
- The team ensured that the mooring ropes are a capable of withstanding maximum environmental conditions via a combination of ANSYS Fluent simulations (based on 40 years of wave data) and analytical models

Ultimately, the limited number of components in the anchoring system is a step towards harvesting wave energy economically and addressing climate change.
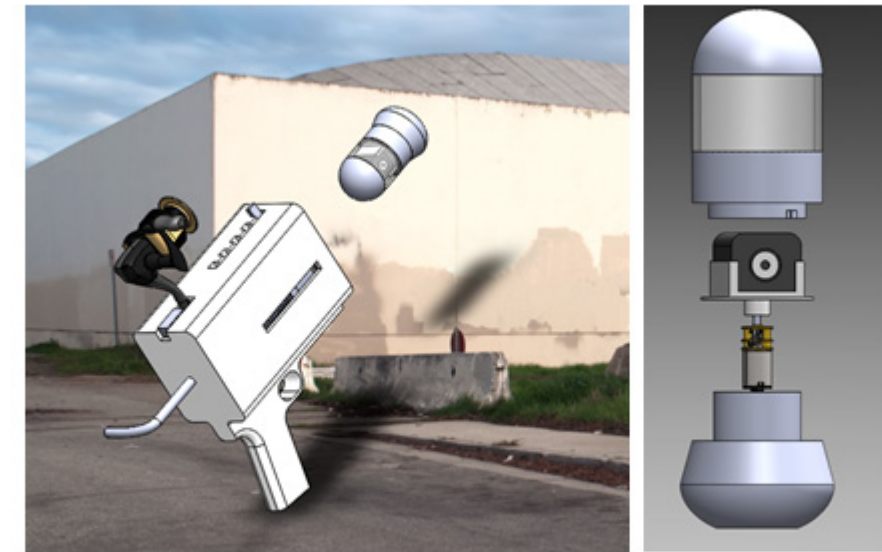
Figure. (Left) Launcher is deploying camera assembly to roof top (not to scale). (Right) Exploded view of camera housing assembly.

Launchable Inspection Camera

Client: Professor Nasser Ashgriz
Team Members: Mohammad Ishaq Khan, Lucas Savedra, Ian Christopher Towe, Yiqian Gao
Supervisor: Nasser Ashgriz

Replacing the ladder with modern technology for self-inspection activities

Currently, the inspection of rooftops and drains requires a ladder, needing two people to transport, set-up, and operate. Thus, making the process time consuming, inconvenient, and unsafe due to injury from falling. An alternative solution to a ladder is to use a drone for inspection, however, drones are prohibitively expensive and are only operable in large open spaces. For these reasons, Dr Ashgriz identified the need for a low-cost tool for remote visual inspection.

The launchable inspection camera provides homeowners and maintenance professionals with a compact handheld tool that allows for visual inspection from a distance. The design requires minimal setup, effort, and instruction to operate, thereby increasing the efficiency of the self-inspection process.

Design Description

The design is comprised of two main parts - the camera housing assembly, and the handheld launcher. The camera assembly uses a Wi-Fi camera that streams live video footage to the user's smartphone. The camera is installed inside of a 3D printed housing where a motor mount rotates it 360o at a rate of 8rpm, via a DC continuous motor. The camera views out of an acrylic window which allows the user to view the target area using the app while protecting internal components from the environment. The housing is designed to imitate a "roly poly" design so that after landing, it uprights itself with a weighted bottom.

The 3D printed launcher fits the entire camera assembly in its barrel containing high force springs. Retracting the metal guide at the back of the launcher compresses the springs which, on release, launch the camera assembly. Attached to the launcher is a fishing reel that will be used to retrieve the device using a strong fishing line.
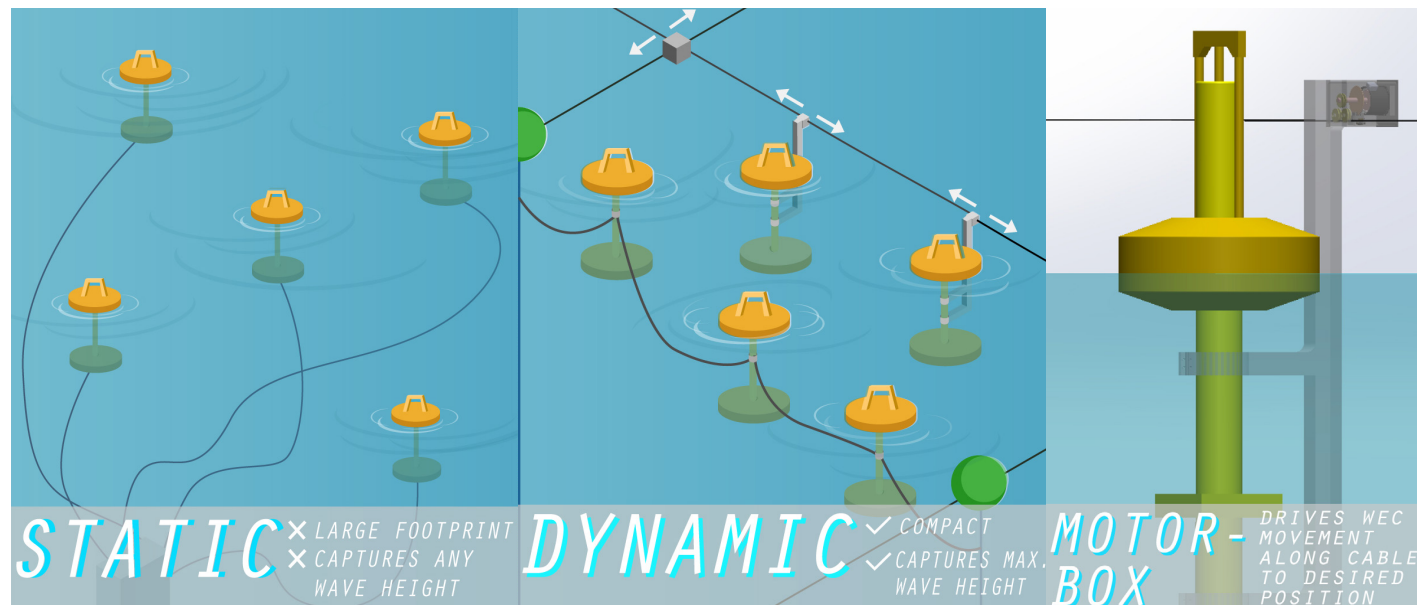
Let's Power UP! Actuation Mechanism for Dynamic WEC System

Client: Wavegen Inc.
Team Members: Jung Eun Baek, Tracey Lem, Yiran Lu
Supervisor: Pierre Sullivan

What's the Gap? - Current systems are not maximizing energy capture

• Renewable energy from ocean waves can be captured through Wave Energy Converters (WEC).
• Currently, WEC farms have them placed far apart to avoid destructive interference from each other, but this is not space efficient!
• WECs are stationary reducing the potential energy capture from each wave as the highest wave is not always captured (taller wave = more energy captured!)
• Wavegen Inc. is a startup that is developing a dynamic WEC system to take advantage of the constructive interference areas created by the array of WECs.

What's the Impact? - The growing need for renewable energy

• Results in an improved efficiency of energy capture from achieving optimal positions.
• Makes wave conversion a more viable renewable energy source to combat increasing fuel prices and energy demands, interest from the government and other fuel/energy companies.
• With the effects of climate change and global warming becoming more severe, the demand for alternative energy sources by the public and environmentalists is increasing.
• A step away from carbon fuels and a step towards a better environmental future.

How to Fill the Gap? - An above-water actuation mechanism

• The team was to develop an actuation mechanism that would:
  1. Maximize energy capture at highest wave amplitudes.
  2. Minimize WEC farm footprint to improve space efficiency.
• An above-water motor box drives a pulley system to move the WEC along a cable.
• Making the mechanism above-water improved on WAVEGEN's current design because it reduces the amount of wear, and allows for easier and cheaper maintenance.
• The design will be WAVEGEN's second iteration of the WEC actuation.
• At its optimal position, the WEC can generate up to 3x the energy!

Solar Driven Convection Dehydrator for Rural Cambodia

Client: World Vision
Team Members: Jeremy Miranda, Manjot Atwal, Michael Bento, Rachel Mandel
Supervisor: Amy Bilton

Addressing malnutrition of children under two in rural and remote Cambodian communities

This project is a collaboration with World Vision to address malnutrition and stunting among vulnerable populations, specifically children under the age of two in rural Cambodia. Though crickets are already commonplace fare in the region, small children without teeth cannot eat them due to the choking hazard they present (Cambodian crickets are much bigger than Canadian ones!). By designing a mechanism to dry and grind crickets into a powder, they will become consumable for children. Crickets have 136% more protein per unit mass than beef steak and have already been shown to be effective in improving the health of children in trials previously conducted by World Vision [1]. The team conducted a Needs-Assessment and spoke with mothers from two communities in the Siem Reap province who affirmed the value of cricket powder for their children. Enabling communities to dry their own crickets for powdering should ameliorate child malnutrition.

Design and implementation of a portable and inexpensive dryer

The final design is a solar convection driven dehydrator, whereby ambient air is drawn into a glazed collector and becomes heated by the sun. The relative humidity of the incoming air is reduced as it becomes hotter and rises through the collector. The heated air flows over the crickets, picking up moisture before being released back into the environment. Heat storage has been incorporated into the collector to minimize temperature peaks inside the chamber and reduce rehydration overnight when the environment cools. The unit was designed to be buildable in Cambodia such that communities are able to create personal dehydrators. Local materials were selected so that profits would be funneled back into the Cambodian economy. The design was required to be inexpensive such that the cost would not be inhibitive to community members interested in investing in a unit. Come feel the heat of our solar dehydrator and taste some homemade crickets!

[1] World Vision, "Proposal, Cambodia Starting Strong", Sotnikum Operation District, 2016.
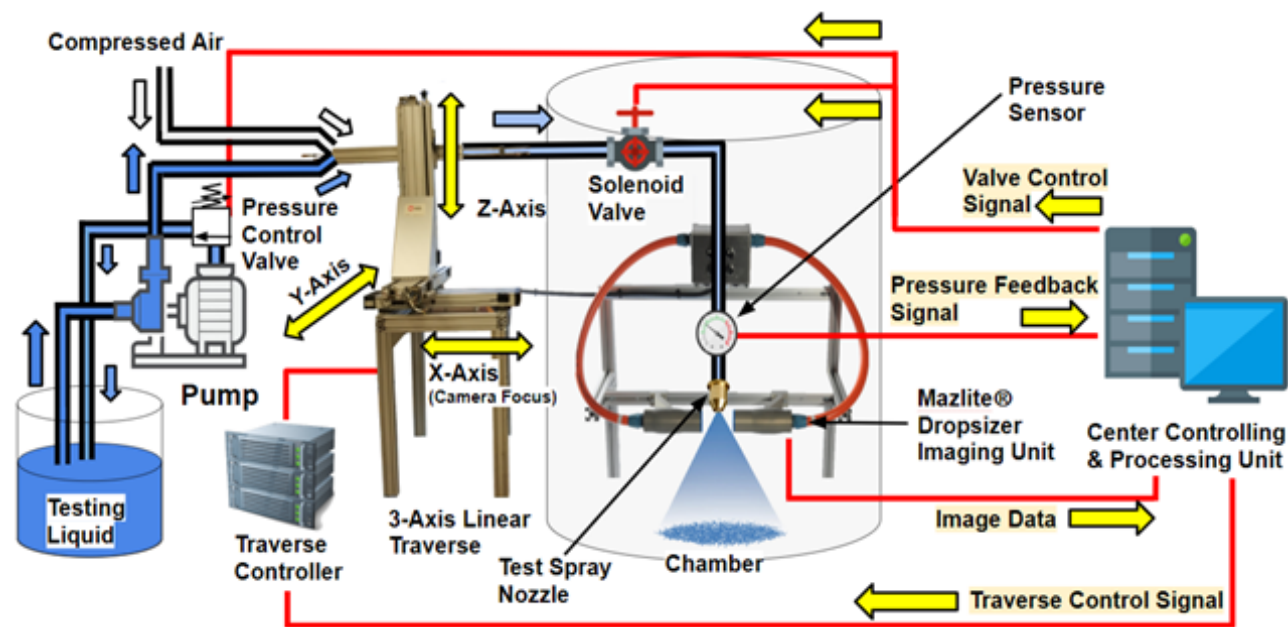
Spray Particle Analysis System Design

Client: Mazlite Inc. Amirreza Amighi
Team Members: Stephen Huang, Yuanshan Du, Hongzheng Xu, Yixiao Hong
Supervisor: Nasser Ashgriz

Importance of Efficiency in Spray Particle Analysis

Atomization is the process of breaking up liquid into finite droplets using a spray system. The technology is widely used in various industries such as pharmaceutical powder production and car body coating. If we can better study and characterize the spray, it would be helpful in industry applications such as ensuring the quality and minimize waste or overspray. The pharmaceutical company will be able to make finer powder; and automotive industries will reduce the waste of car painting.

The "DropSizer" is a portable device developed by our client, Mazlite inc. to monitor spray atomization. Although the device works, it requires frequent manual interference which results in inefficiency. As a result, the client wishes to design a semi-automated system that can complete large amount of tests in a timely manner. To do so, serval existing and newly purchased components are integrated into the designed layout.

By implementing this design, the DropSizer's setup time was reduced by 340%. The overall test efficiency was increased by 220%. Due to the implementation of the traverse unit, the positional accuracy improved significantly (+/- 0.0125 mm). Thanks to the increased efficiency and accuracy, this system can be used to perform extensive testing with minimal human supervision.

Overview of Semi-Automated System and Design Concept

The team applied the concepts of design for ergonomics and design for safety to create a user friendly and safe testing environment.
The design consists of three systems that are all connected to a central control unit.

Traverse System: The traverse unit adjusts the nozzle position using cartesian coordinates.

Spray Control System: Controls the spray pressure with electronic pressure regulators and solenoid valves.

Image Capturing System: Integrates the DropSizer image capturing and analyzing system as the central part of the entire design.

Thermoelectric Cooling Technology for Preservation of Manuscripts

Team Members: Carole Suarez, Meherin Mushrekat, Raneem Shammas, Ajani Vijayakumaran
Supervisor: Markus Bussmann

Existing Need and Impact

India's rich history and repository of knowledge has been documented on palm leaf, vellum and paper manuscripts for generations. Low income families and monasteries are experiencing difficulty protecting these delicate texts from rapid deterioration under South India's extreme humidity and climate fluctuations. Similar situations are present in other developing areas within India and around the world. To address this global need, the team provides a low-cost solution that is adaptable to various environments.

Design Solution

The solution is a cost-efficient, insulated compartment that preserves manuscripts in a controlled environment of 21°C and 50% relative humidity. The compartment will be made of materials that can be locally sourced to minimize costs of manufacturing. The box will be constructed with wood or bamboo, with an inner foam insulation and a thermoelectric cooling system. Humidity is managed by condensing moisture out of the air using recycled electronics such as heat sinks, Peltier chips and fans. Fans allow the circulation of air to and from the compartment, while a current that passes through the Peltier chips creates a temperature difference on either side of the chip. The heat sink connects to the cold side of the chip and allows the inside air to cool down as it flows through the fins of the chips.

Compared to an incandescent light bulb of 60 W, the thermoelectric setup when connected to a 12V battery uses 33% less power and a projected lifespan of 800 hours. The fairly novel method of thermoelectric cooling was adapted into the prototype and further verified using simulated thermal analyses and testing to ensure feasibility of the product. The prototype results were then scaled using calculations for three manufacturable sizes so that the design can be used to store multiple sizes of manuscript collections.

Finance and Risk Management
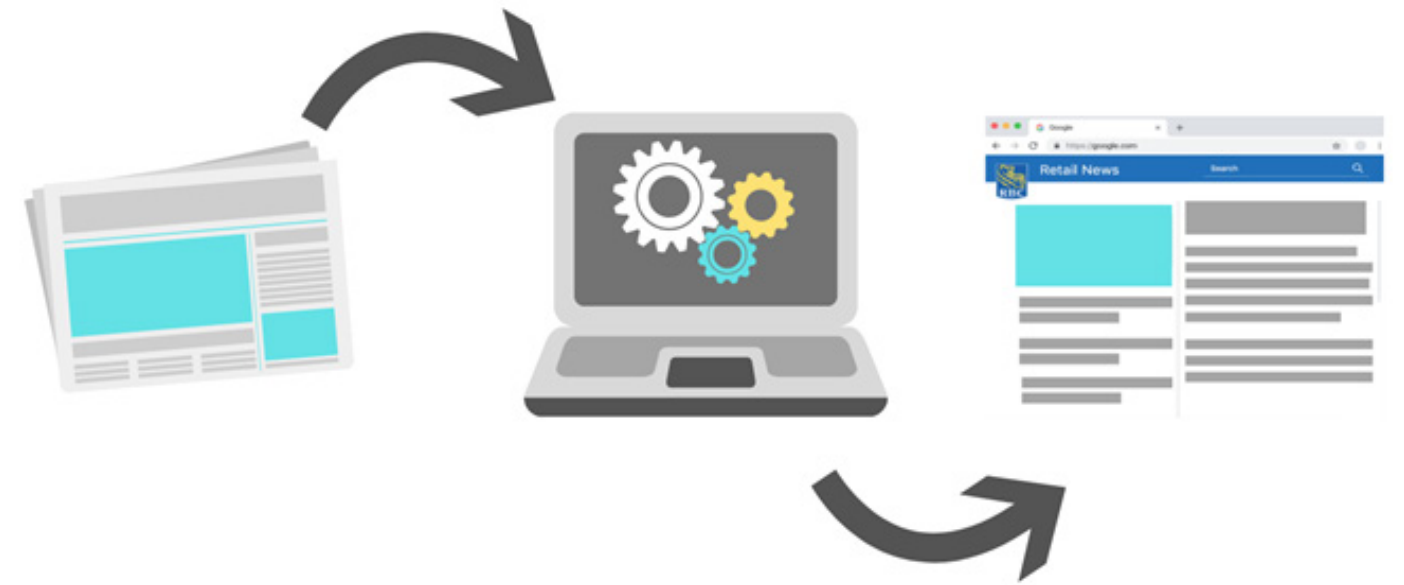
Daily Market Moving News - Curated by Machine Learning

Client: RBC
Team Members: Jessie Diep, Ayan Gedleh, Jade Khiev, Padmanie Maulkhan
Supervisor: Scott Sanner

Providing a real-time overview of the news that impacts investors

Over 2 million articles are posted online every day but only a select few can help RBC Business Financial Services Advisors help their clients make better investment decisions. Articles on events that affect the market are referred to as "market-moving news". As it stands, Financial Advisors (FAs) sporadically share market moving news amongst themselves, but have no formalized system. As a result, this inefficient process is both unreliable and prone to bias.

Our application provides FAs with an overview of the latest market-moving news, so that they better help their clients to invest. This application leverages multiple machine learning (ML) algorithms to identify market-moving news and enables advisors to skim content, as well as drill down into topics of interest. To eliminate individual bias, the application also takes feedback from all users to further refine its definition of market-moving news.

A dashboard powered by multiple machine learning algorithms

When a user opens the dashboard, a fresh set of news articles is pulled from 20 of the most popular and reliable business news sources. These articles are fed to a logistic regression algorithm that classifies new articles as market-moving or not. Next, additional ML techniques are used to recommend related articles, extract key context tags, and highlight key phrases.

Significant research has been conducted on predicting market-moving news, but the results have been inconsistent because "market moving" can be subjective and varied across industries. Our application has been fine-tuned to find market-moving news in one of RBC's most heavily traded industries, the retail industry. This combination of machine learning algorithms and a graphical user interface leverages the power of machine and human intelligence to allow investors to find the news that they believe to be impactful.

Current Process: Require device
Check lab for device → If unavailable → Send mass emails → ✉ → Wait for replies → ✉ → Wait for device to be returned → Acquire device

Improved Process: Require device
Check CHEQROOM for device → If unavailable → Book device → Wait for device to be returned → Acquire device

CHEQROOM Application

Create custom experiments with a series of images and questions

TD Design Research App

Design Experiment | Run Experiment

Run experiment and save participant data for analysis

Improving Inventory Management at TD Design Research

Client: TD Design Research - Ryan Kealey
Team members: Vicky Li, Vithushiha Selvakumar, Mehrali Ahmadli
Supervisor: Mark Chignell

Project Overview and Objectives

To conduct research studies at TD Design Research, design researchers use various technologies such as eye trackers, wrist sensors, tablets and mobile phones. Using these devices is a fundamental step in completing research studies and moving forward. Currently, the process in managing all the lab equipment is disorganized and scattered. As a result, the team has come up with a solution that will improve the inventory management process at TD Design Research while meeting the following objectives:

• Feasibility • Usability • Durability • Efficiency • Minimal interference • Aesthetics

Design Process
The project was a highly-iterative process. Below were the steps the team took to identify the problem, ideate solutions, and finalize a design:
Preliminary Research
• Conducted interviews with design researchers
• Refined problem statement
Conceptual Design
• Generated candidate designs, evaluated each based on objectives and chose best design
Design Review
• Further evaluated chosen design and decided to change it due to project constraints
• Submitted design change proposal
Detailed Design
• Created process maps and implementation plan
Testing and Analysis
• Conducted user testing with final design and analyzed improvement areas

Final Design
To eliminate the current need of mass-emailing all employees regarding equipment whereabouts, the CHEQROOM mobile cloud application was incorporated to optimize inventory management. The team also provided the client with a guideline demonstrating the optimal process for frequently used features on CHEQROOM. This design will allow the researchers to easily:
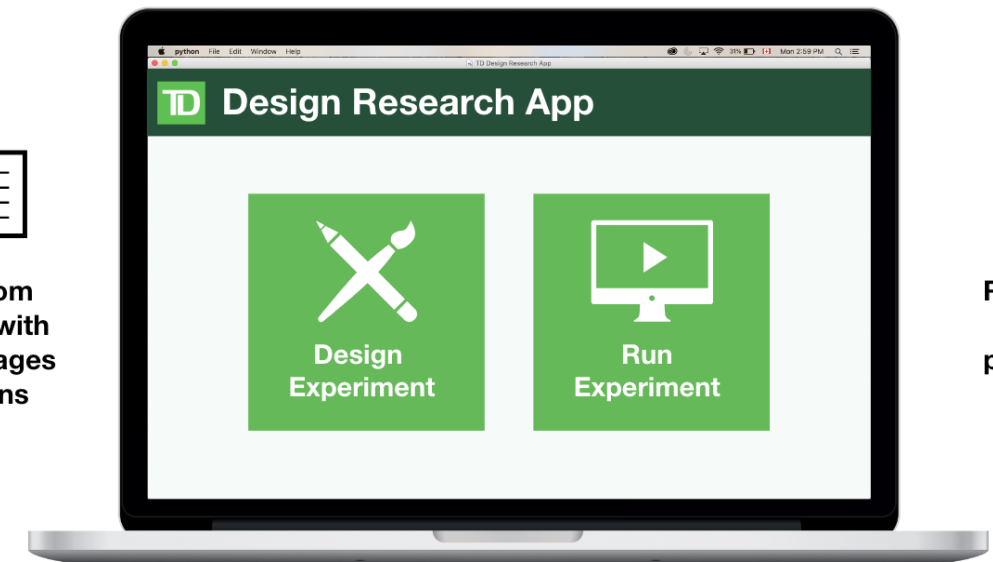• Keep track of equipment
• Add new equipment
• View device availability
• Schedule equipment
• Add user information

Impact
• Shortens the delay acquiring devices, thereby increasing the overall efficiency in conducting research studies
• Clear communication when scheduling devices via CHEQROOM

Providing New Psychology Research Capabilities at TD

Client: TD Design Research Team
Team Members: Shaina Hantsis, Amanda Albaba, Ahely Shemontee, Nima Mirjalali
Supervisor: Greg Jamieson

Impact of the Psychology Experiment Platform

The Design Research team at TD supports the design and development of internal and client-facing platforms. The team conducts project-based experiments to identify user needs and usability patterns. These projects run across digital and non-digital channels such as telephone, digital banking, and retail branches.

The TD team seeks a platform to conduct Aesthetics Performance Testing. This type of test analyzes the aesthetic of a design through the presentation of a series of stimuli and follow-up questions. Existing platforms do not provide sufficient customizability, data security, and affordability to match their needs. The developed platform by the capstone team enables users to design experiments and provide capabilities to perform the following:

Design Aesthetics Performance Tests   Identify Contributing Attributes to Visual Appeal
Facilitate Studies on Human Cognition   Study Time Required to Create a First Impression

Meeting the TD Design Research Team's Needs

The platform was developed using an iterative user-centered design approach to capture and focus on the whole user experience. The fully functioning application solves the client's three main needs:
1. **Customizability:** a variety of experiments can be created via stimuli and question screen pairings
2. **Data Security**: operates offline and stores experiment data on the local computer
3. **Affordability**: allows for future improvements that can be developed internally using Python

Created experiments can be saved and shared within the Design Research team for further analysis. The designed experiments may be saved for future use or further editing.

Healthcare/Social Services

2a. InspectRX Medication Verification

3. Technicians Check at Viewing Station

5. Happy Patients!

1. ATP Unit Dose Machine Dispense Medications

2b. Technicians Handpick & Scan Non-ATP Unit Dose Medications

4. Cart-fill Ready for Delivery
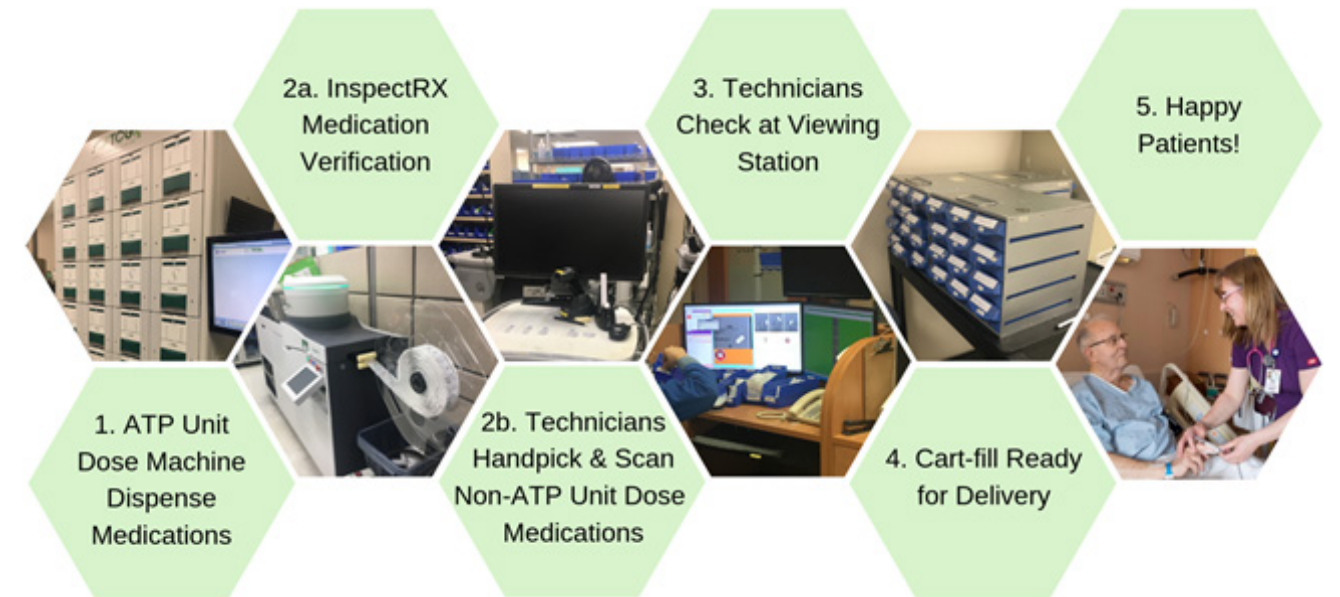
Analyzing Resource Savings for New Inpatient Cart-fill Process

Client: North York General Hospital Pharmacy Unit, Patient Experience & Quality Unit
Team Members: Xuanhui Chen, Sharlene Peng, Ye Xiang, Juntian Zhang
Supervisor: Michael W. Carter

Modelling and quantifying resources for cart-fill prescriptions

The cart-fill process is a common pharmacy practice where technicians fill each patient's medication drawer from a prescription fill list twenty-four hours in advance. NYGH's pharmacy unit has added a new Automatic Tablet Packaging (ATP) machine and a Medication Verification System (InspectRX) to improve the 24 hour inpatient cart-fill process. The use of automation technology improves the efficiency and safety of medication distribution at the point of care and acts as an essential component of their pharmacy practice. The new process being implemented for the machines gives the team at NYGH an opportunity to quantify the potential resource savings of the new process while also developing a more sophisticated method of quantifying workload.

Decision analysis model to measure technician's workload

The goal of the project is to create a model that compares the current and new process to present a preliminary resource savings as a percentage improvement. The model takes various factors into account including varying task unit times, decision points such as using the tray, error rates, and prescription distributions. Due to the data limitation of modelling a process that hasn't been fully implemented, decision analysis relies on the knowledge and understanding of experts on the NYGH team and allows the team to update these assumption once more data can be collected. The model of the new process produces a workload measurement in hours, allowing the Patient Experience & Quality Unit to closely work with the Pharmacy team to update their expectations for resource requirements and build a mutual understanding of workload measurement in the future.

Prototype

Force Sensor
Scrolling Wheel
Buttons for
Modes Switching

Image Scrolling using Force Sensor for Radiologists

Client: Trillium Health Services
Team Members: Zhen Yan Wang, Jeremy Tsoi, Haoming Wang, Ziwei Xu
Supervisor: Paul Milgram

### Alleviating muscle strain while scrolling through images

Currently the Radiologists at Trillium Health Partners (THP) utilize the standard computer mouse with a scroll wheel for scrolling through thousands of images (MRI and CT scans of patients) on their Picture Archiving and Communication System (PACS). This leads to potential Musculoskeletal Disorders (MSDs), such as Carpal Tunnel and Trigger Finger Syndrome, from the repetitive constant motion of vertical scrolling with the middle finger.

The objective for this project is to redesign the current computer mouse, specifically to cater for the main function of scrolling for the radiologists.

The final design will provide radiologists at THP, the means to complete their work in a safer setting. The design will help alleviate the muscle strain experienced by these specialists and the potential to indirectly reduce costs. Future implementation iterations would include customizable software settings. A successful design can impact the radiologists, not only at THP, but in a global scale.

How we achieved it: a speed control design with force sensor

Final prototype is a gaming mouse with a force sensitive joystick attached at the front of scrolling wheel. User can scroll through pages by pushing the force sensor forward or backward while pressing the mode switching button at the same time.The force sensor provides user speed control. By applying greater force, the scrolling speed will be greater as well. The scrolling wheel is kept for precise scrolling. This mouse with force sensor has a better result in scrolling speed test against regular mouse.
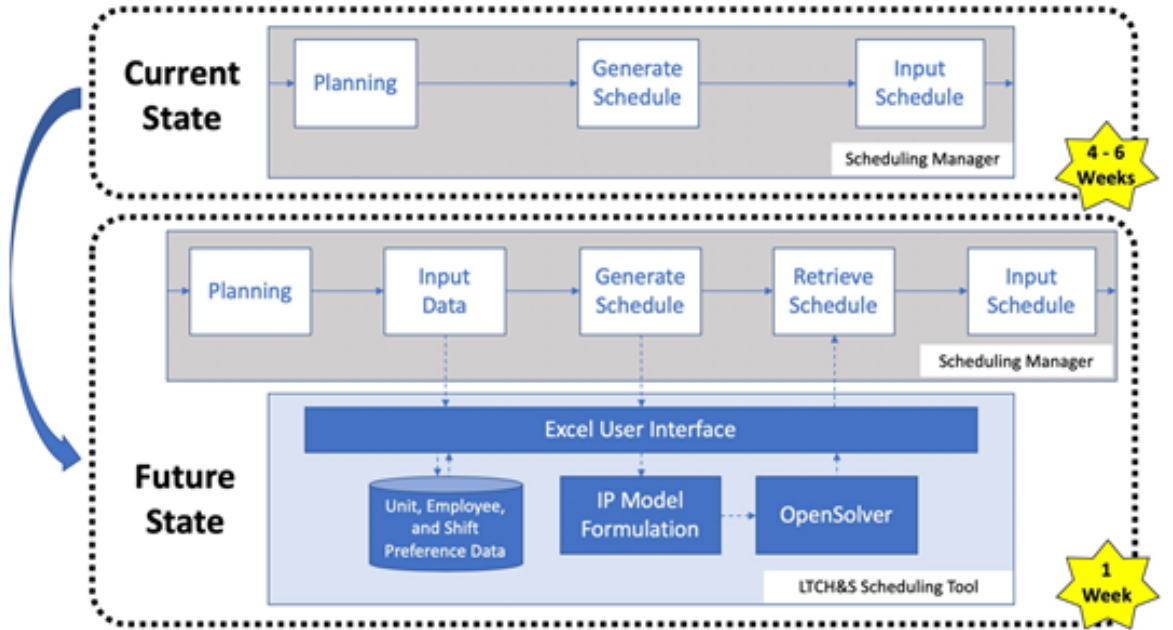
Improving Resident Care at Toronto's Long-Term Care Homes using Scheduling Optimization and Automation

Client: City of Toronto Long-Term Care Homes and Services (LTCH&S)
Team Members: Manion Anderson, Quinton Lowe, Scott Rathwell, Dan Yang Yan
Supervisor: Vahid Sarhangian

Using automation to allow nurse managers to do what's most important - caring for their residents

Nurse managers at the City of Toronto LTCH&S division currently devote up to 60% of their time on scheduling-related activities; time better spent on improving resident care. These activities include building and revising schedules, while taking into account nurse preferences, union agreements, and labor constraints. Despite these efforts, 10% of all shifts are not worked as scheduled, resulting in significant additional scheduling work.

In this project, we develop a solution that automates the process of scheduling nurses to shifts while maximizing shift preference for nurses and other care providers: this will significantly reduce the time to build schedules and the need for revisions. In addition, we expect the incorporation of shift preferences to reduce absenteeism. Few scheduling solutions currently offered in the healthcare sector include automated schedule generation, and fewer still account for shift preferences: our solution is a step in improving the systems that support long-term care.

Improving resident care and the work environment through scheduling optimization and automation

The scheduling solution consists of a user interface (UI) and an integer programming model (IP). The UI was developed in Excel using VBA (Visual Basic for Applications) and enables a user to input Scheduling Unit, Employee, Shift Preference, and Vacation data. This data is the input to the IP, which allow users to generate a feasible schedule optimized for preferences (ranking availabilities from 1 to 3, 1 being most preferred) while satisfying constraints on seniority, overtime, union agreements, and labor regulations.

Our proposed solution has the potential of significantly improving resident care and nurse satisfaction across nursing homes in Toronto. The scheduling solution is currently being prepared for a three-stage pilot across 6 scheduling units in 3 homes, with plans for a city-wide implementation across all 10 long-term care homes; potentially impacting 2,640 residents and over 3,400 nursing staff.
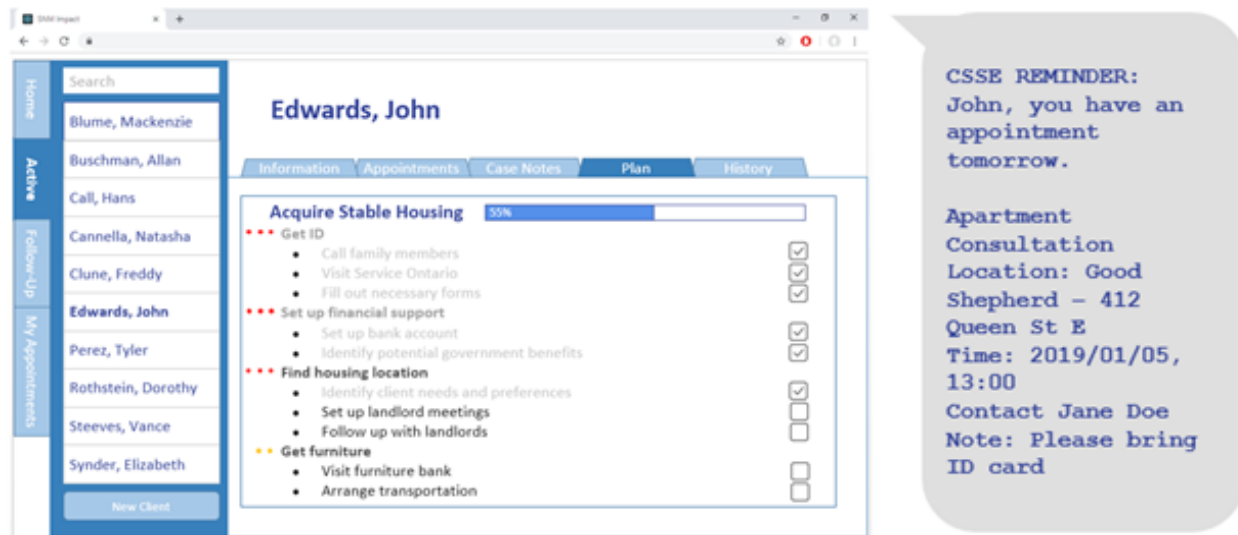
Figure 1 (left): Client view in the Case Manager's application, showing goals, sub-goals, and the progress towards said goals.
Figure 2 (right): An automatic SMS update from the application, reminding a Client about an appointment.

Improving Social Service Client Outcomes with Stories

Client: Centre for Social Services Engineering (CSSE)
Team Members: Simon Andre, Stephen Gidge, Brandon Lista, Theresa Taylor
Supervisor: Mark S. Fox

Social Service Clients are Not Completing their Plans

Social service providers are having major issues with their Clients not completing their service plans for betterment. Currently, service providers do not know why this is the case, and further, do not have the data required to fully understand the issue. Case Managers, who work with Clients to develop a plan, need an all-in-one solution to improve the effectiveness of social services. This is done through enabling efficient client management, encouraging plan completion, and collecting and analyzing data on Client outcomes. All with the objective of Clients completing their plans and thusly, bettering their lives. Social service providers working with the CSSE would come to benefit from a solution as it would reduce redundancy, motivate Clients, and allow one to see the big picture of a Client's journey through social services.

Harnessing the Client's *Story* to Better their Outcomes

Our design provides Case Managers with a centralized platform to record Client information, create plans and goals, and set up automated SMS reminders for Clients. Goals, such as obtain stable housing, get identification, etc., are dependent on the Client's situation. The design places heavy focus on the Client's story by allowing a Case Manager to view past records of where the Client received services and other pertinent information. This will ensure that organizations serving a Client avoid duplicating work, as well as allow them to view their Client's service history. Additionally, SMS messages encourage Clients to attend meetings related to their plans, as well as giving them a platform to provide feedback on service quality, a functionality that existing applications do not have. Through the use of the application, and it's SMS features, information will be elicited allowing Case Managers to better understand areas of the plan where Clients fall short in order to tailor plans to their individual needs, as well as improving overall service and client outcomes.

Optimization of the Hospital Portering Process

Client: North York General Hospital
Team Members: Huiqing Lu, Jia Qi Xi, Jiayue Niu, Pratana Charoenkitkarn
Supervisor: Michael W. Carter

Transporting patients and resources to a different unit in the hospital efficiently

The process of transporting patients and resources between healthcare units and service areas, also known as portering, is critical for North York General Hospital's (NYGH) daily operations. Currently, dispatchers manually assign tasks to porters, who will receive the task information via a Pivot device, based on the availability of porters and urgency of requested tasks. Inefficient portering processes lead to higher costs and longer wait time for both patients and the hospital staff; hence, NYGH's portering department aims to find a solution to meet its Key Performance Indicators (KPIs).

Matching porters' working hours with dynamically forecasted demands

After developing three alternatives with cost-benefit analysis, the team has decided to proceed with a scheduling solution. The final scheduling algorithm allows the portering department to schedule porters according to hourly task volume for each day of the week and can be easily updated with the latest demand forecast. The solution was designed to have most of the steps automated, including historical data analysis and forecasting of future demands, in order to minimize manual steps.

Impact on the healthcare industry

The team's final solution has enabled a more efficient portering process in NYGH, which means faster service and more satisfied patients. Many other hospitals are also facing similar portering issues caused by the process complexity and large task volumes. As the proposed scheduling algorithm is relatively simple to adjust based on any unique constraints, other hospitals can modify the algorithm to better fit their environment. With a better portering process, hospitals can improve the overall efficiency and quality of their daily healthcare services, which saves costs and improves patient and staff satisfaction.
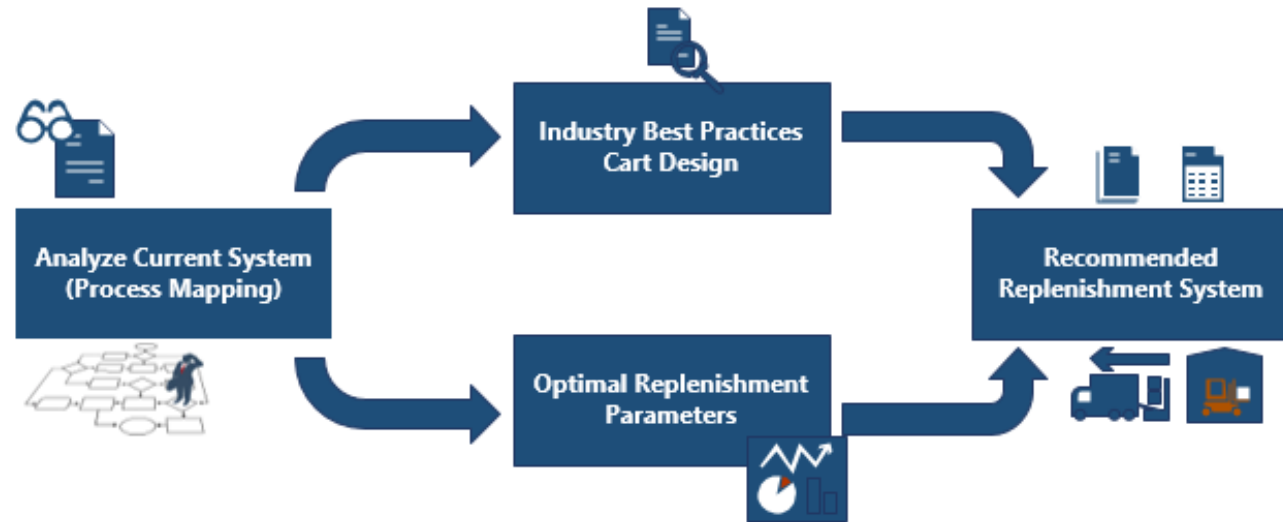
Optimizing Medical Supply Cart Layout and Replenishment Process

Client: North York General Hospital
Team Members: Prabhat Adhikari, Christopher Cheng, Jong Seo Park, Saiyu Sheng
Supervisor: Michael W. Carter

Improving Patient Quality of Care through Medical Supply Cart Optimization

North York General Hospital (NYGH) has issues with their inventory management process for medical supply wards resulting in overstock/understock, and slow retrieval times. The objective of the project is to minimize the time nurses spend retrieving medical supplies so they can redirect their time to improve quality of care for the patients. The project also allows the hospital to optimize their inventory levels so they have a low probability of stockout as well as identifying and eliminating excess inventory.

Since inventory control and stock organization is a challenge faced by many hospitals, this project can provide insights to hospitals for better managing their replenishment systems. This ultimately translates into better healthcare to the patient as each dollar amount saved from inventory problems can be put into obtaining better facilities, equipment, and services for the patient.

Multifaceted Solution to Supply Cart Optimization Problem

First, process mapping of replenishment system was done to identify issues affecting inventory levels. To minimize the supply retrieval times, recommendations on the layout of the supply carts were made based on best practices in other hospitals, Lean Principles as well as Human Factors considerations. For changing replenishment parameters to mitigate the overstock/understock issues, an ABC Analysis was performed to prioritize the key items having the most impact on inventory costs. For these items, optimal inventory levels were calculated based on the tradeoff of different service levels and the resulting costs of inventory. The recommendations are designed so that NYGH staff can implement the applicable solutions immediately as well as work towards addressing the gaps present in the current replenishment system.

Predicting Inpatient Bed Demand in North York General Hospital

Client: North York General Hospital
Team Members: Xiying Li, Francisco Vargas, Yuhong Yang, Kexin Zhang
Supervisor: Michael W. Carter

Understanding Congestion in Units & Improving through Optimizing Operating Room Schedule

North York General Hospital (NYGH) has over 30,000 inpatient volumes annually, with a limited number of staffed beds in the surgical units for patients who stay overnight (inpatients). Congestion has been reported in the units which has negative impacts on upstream inpatient flow such as longer waiting time and more cancellations. Therefore, the client requested our team to investigate the current bed utilization in surgical units and make recommendations for improvements.

Our team has identified inpatient bed demand through a simulation model, and through an optimization algorithm we reduced the peak demand of the week by swapping operating room (OR) blocks in the schedule. This results in more efficient use of the currently available resources which allows the hospital to potentially accept more surgeries, shorten waiting time, and prevent surgery cancellations.

Simulation & Optimization: Identify and Smooth Bed Demand for a Typical Week

The simulation model first defines arrival distributions for elective and emergent patients respectively, using the historical surgical records and the OR master schedule. Then, it generates random patient arrivals according to the distributions defined and match each arrival with a historical record. With information about length of stay in the OR and units, the model calculates the patient volume for each day of the week. In total, 50 trials were run and the hospital bed demand is set to be the maximum daily patient demand of the week that satisfies 90% of the trials. Through pairwise swapping on OR schedule, the improved schedule leads to an approximately 9% decrease on the bed demand for elective patients when limiting swaps to only between OR with same type of surgeries.

Predictive Model for PD Hearth Program

Client: World Vision
Team Members: Hsiang-Yi Wang, Louie Li, NanNan Liu, Guang Yang
Supervisor: Mariano P. Consens

### Predicting Weight Gain for Malnourished Children

World Vision has executed the Positive Deviance/Hearth (PD Hearth) program for several years to treat children suffering from malnutrition. Through this program, they have established an extensive set of raw data. By analyzing this data, we have developed a predictive model that World Vision can use for children being treated in the program in the future.

By creating a predictive model, we can provide World Vision with valuable information that they can consider when treating children with malnutrition in the PD Hearth program. The model predicts the weight a child is able to gain by day 30 and with this information, World Vision can predict whether the child will recover and whether additional help or resources are necessary for a given area. The main objective of the model is accuracy: the model should provide results that have a percentage error less than 20%.

Model Overview and Results

Data sanitation was performed and then three predictive models were implemented: random forest, decision tree and linear regression. Random forest has the most stable and accurate performance and was chosen as our final model.

A random forest is a machine learning predictive model that builds multiple decision trees and merges them together to get a better prediction compared to a regular decision tree. The inputs of the model are the children's sex, country, day 1 age and weight. The output is the predicted day 30 weight of the children. The random forest is able to predict day 30 weight with only 4.33% error.
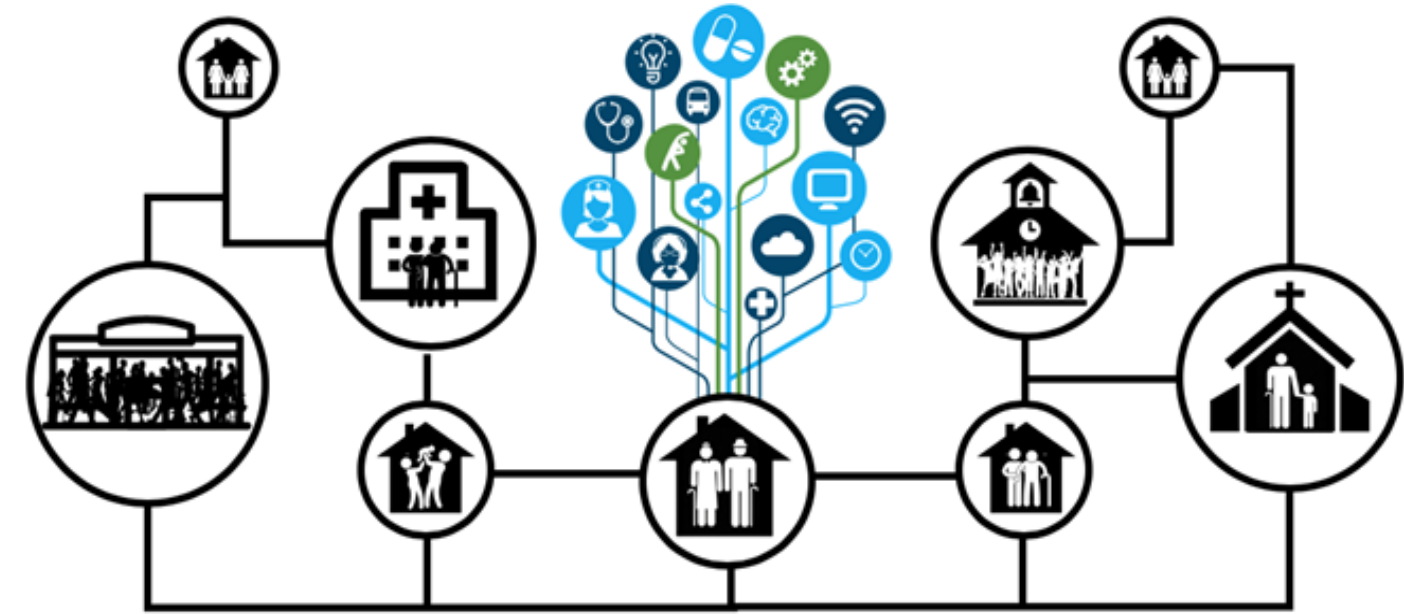
# Re-Engineering the Healthcare Experience for Seniors

Client: PricewaterhouseCoopers
Team Members: Syeda Areeba Aziz, Amanda King, Sarah Esmail, Hira Nadeem
Supervisor: Birsen Donmez

The Canadian healthcare system fails to meet the needs of seniors

The Canadian healthcare system was designed over fifty years ago with little consideration given to the social determinants of health, specifically for seniors. Healthcare was centered around physicians and hospitals rather than the user experience. As a result, the system fails to support aging Canadians with only 45% of seniors able to get next day appointments when they are sick, 16% having professionals that check in with them between doctor visits, and 41% with access to after-hour care. The project team was asked by the client, PricewaterhouseCoopers, to design a vision of the transformed healthcare experience for seniors to address these challenges. The real world impact of this vision will be to generate a conversation with healthcare professionals on the improvements that can be made to the healthcare system. These changes would benefit all members of the system including seniors, the friends and family of seniors and healthcare practitioners.

The team re-engineered the healthcare experience through a unique approach to user research

The final design is a storyboard that indicates how our solution works together to transform the seniors' healthcare experience. The components of the solution include a campus of care setting that provides centralized services, a caseworker to liaise between healthcare practitioners, augmented reality to improve the accessibility of health and wellness services and a consolidated information sharing system. The solution addresses the key problems identified through our unique approach to user research including literature reviews, user interviews, design thinking workshops and strategic foresight. The design thinking workshops were hosted with seniors, academics, and healthcare consultants to ensure the team had various perspectives when prioritizing problems. Strategic foresight was used to build out potential future scenarios for the healthcare system to ensure our solution addressed not only the problems of today, but also the problems of tomorrow. As a result of this approach, the team is confident in the transformed experience.
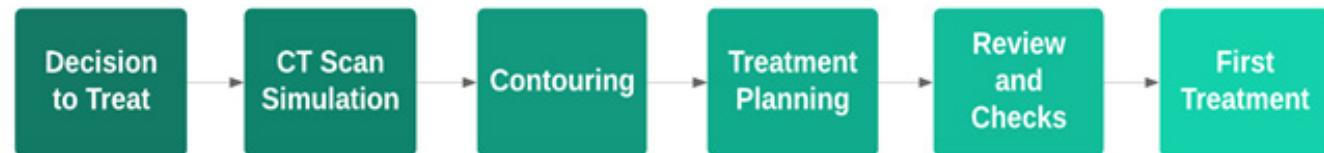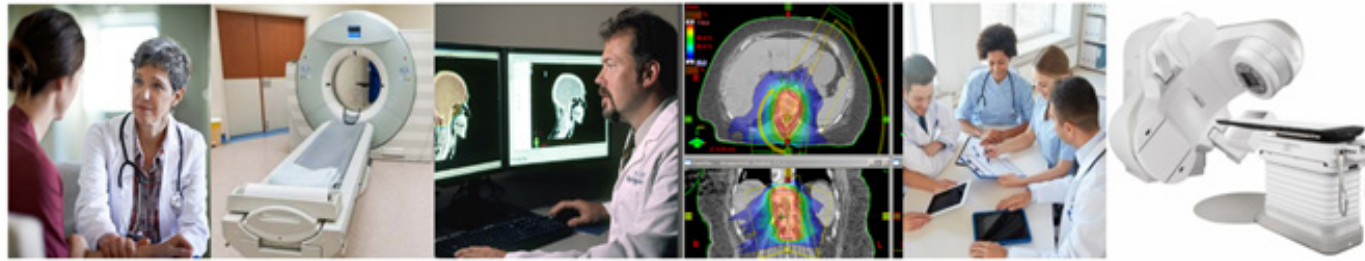
Reducing Patient Wait Times: Radiotherapy Preparation Process Bottleneck Identification and Efficiency Improvement

Client: Odette Cancer Centre, Sunnybrook Health Sciences Centre
Team Members: Yuning Chen, Fan Jia, Xueheng Wang, Xiarui Xie
Supervisor: Dionne M. Aleman

Prolonged patient wait times caused by inefficient radiotherapy preparation process

Currently, the Odette Cancer Center (OCC) at Sunnybrook Health Sciences Centre follows the six stages shown in the process diagram above to prepare radiotherapy for cancer patients.
- Process inefficiency between "decision to treat" to "first treatment" results in prolonged wait times
- Prolonged waiting times decrease patient satisfaction and may have an adverse effect on radiotherapy outcomes
- Bottlenecks during the preparation process need to be identified to reduce wait times

Bottlenecks Identified and Wait Time Reduced with Simulation Modeling & Lean Philosophy

- **Simulation model** provides a dynamic visualization of patient congestions and bottlenecks in the work flow to identify inefficiencies
    o Process changes can be tested to evaluate potential process improvement opportunities
- **Lean analysis** eliminates waste and streamlines processes
    o Non-value-adding activities, such as time wasted by looking for equipment, patient no-shows, and miscommunications between team members, can be identified and reduced

Business Process Management Improves Efficiency at Healthcare Organizations

- Human and facility resources will be better utilized, allowing more patients to get treatment sooner
- Business process management is introduced at OCC to improve healthcare efficiency and deliver better healthcare services
- The project can be used as a reference for other cancer centers or healthcare organizations who aims to provide better treatment experience for patients

HR Planning and Scheduling

High-Level Overview of the Prediction Model
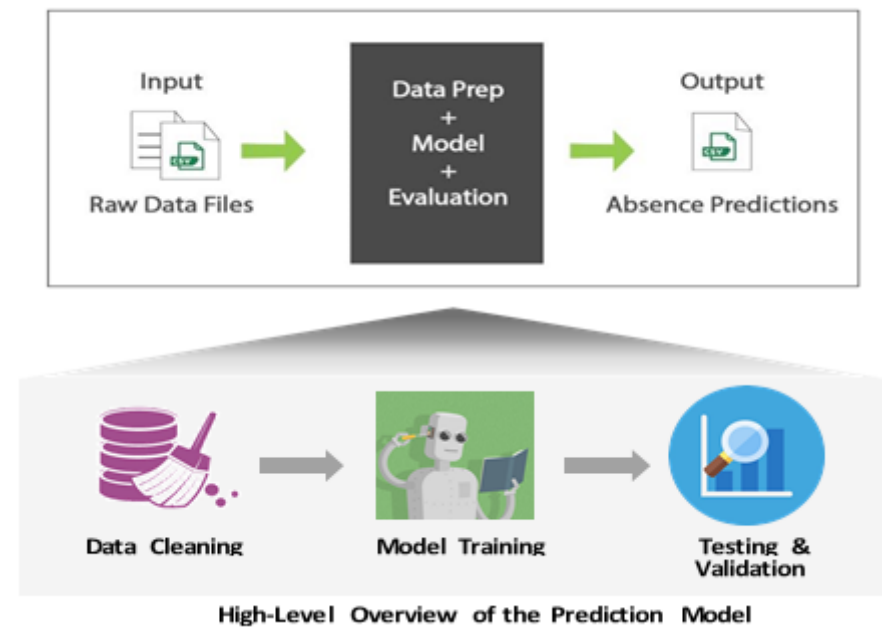
Air Canada: Predicting Flight Crew Absences

Client: Air Canada
Team Members: Mark Charanduk, Kevin Xu, Youngmo Byun, Saurabh Agrawal
Supervisor: Merve Bodur

The Highly Uncertain Nature of Flight Crew Absences

Air Canada is among the largest airlines in North America, dealing with millions of passengers per year. To handle these enormous figures, Air Canada schedules their flight crew rosters many months in advance. Unforeseen absences can result in logistical nightmares and substantial operational costs. The problem consists of finding an efficient, easy to implement, user-friendly solution to accurately predict absences for the long term.

Currently, Air Canada predicts future absences by using a historical average of absence levels, which may be limited in providing accurate insights for future absences. A model that takes into account a multitude of factors affecting absences may be better equipped to improve prediction accuracy and planning operational efficiency.

### Accurately Predicting Absences Drives Cost Savings

The prediction model developed will allow Air Canada to quickly generate accurate predictions for flight attendant absences, up to 18 months ahead of time. Improving prediction accuracy will enable Air Canada to make better staffing decisions that satisfy scheduling constraints, while driving cost savings related to staffing. The project team will provide Air Canada with a better understanding about the nature of flight attendant absences, providing insights into the key factors which affect the duration and frequency of absences.

Leveraging Data to Create a Machine Learning Model

The team developed a prediction model with the following objectives in mind:
  • Develop a model for a dynamically changing flight crew population
  • Automate the flight crew absence prediction process to save time, capital, and effort

The developed solution begins by receiving raw absence data inputted by the client, followed by running machine learning algorithms on the data to predict future absences. The final output is the predicted number of absences over a specified time period, illustrated in the figure below. Training and testing the model over many iterations allowed the team to identify significant features and trends that affect flight crew absences. This enabled the team to improve the prediction accuracy of flight crew absences.
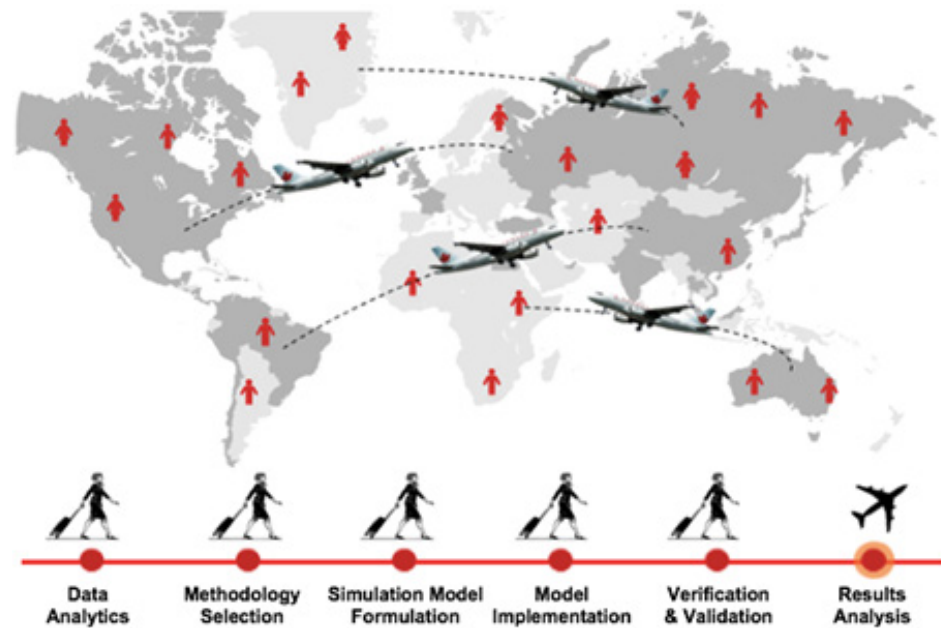
# Air Canada: Simulating On-Call Flight Attendant Requirements

Client: Air Canada
Team Members: Botisola Babayato, Karin Nonomura, Rubaina Nizar
Supervisor: Merve Bodur

Revamping Air Canada's On-Call Scheduling Process

Upon Air Canada's request, the project team was faced with the challenge of predicting the demand for on-call flight attendants (i.e. reserves) on a monthly basis. Air Canada does not update or re-optimized their reserve levels on a regular basis, and a fixed monthly percentage of total crew are allocated to become reserves. Therefore, the team's goal is to replace the current static numbers with a dynamic and data driven derivation of reserve requirements. As a result, Air Canada will be able to further solidify their competitive advantage in the industry through data analytics and advanced technical tools. The overestimation of reserves leads to wasted wages and idle reserves. However, their underestimation requires that regular crew members fly at a 50% premium, significantly driving up costs. In the worst case, flights will be rescheduled/cancelled due to insufficient crew which negatively influences Air Canada's reputation. As such, accurate reserve forecasting will lead to decreased operational labour costs, improved crew productivity and reduction in reputational risk.

Incorporating Discrete Event Simulation in Air Canada's Scheduling

Following data analytics, the team began methodology selection which proved challenging since the process of replacing absent flight attendants involves a high level of variability. The team suggested using simulation, which had not been previously considered for this particular problem, rather than utilizing the proposed approach of optimization. Simulation was selected due to its ability to imitate the dynamic and sequential process used by Air Canada to fill open times (i.e. flights with absent flight attendants). The main input into the simulation model is the flight schedule and the major output is the monthly reserve requirements. The produced model can be built upon to accommodate future extensions, such as the incorporation of optimization to further facilitate the efficiency of reserve scheduling.
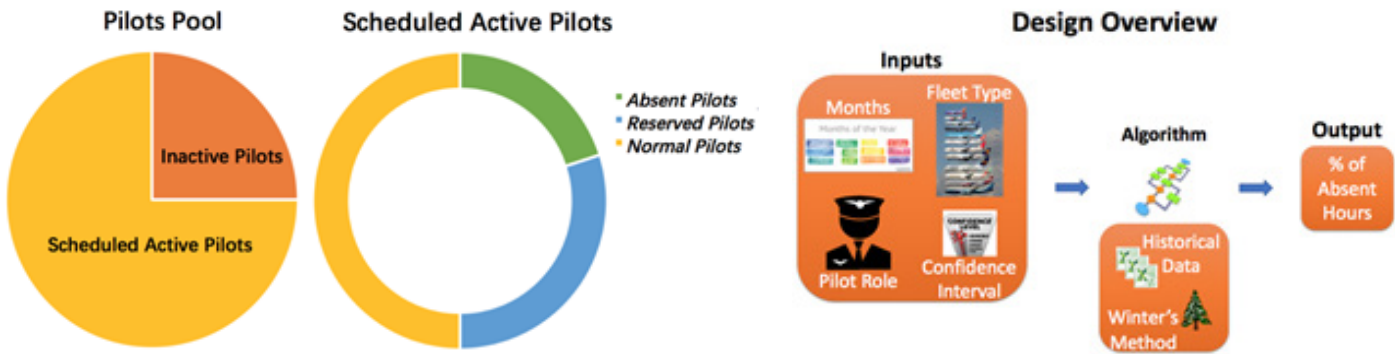
Forecasting the Level of Pilot Absenteeism

Client: Air Canada
Team Members: Haosheng Zhang, Haolin Tang, Jiazheng Li, Bingxuan Wang
Supervisor: Daniel Frances

Preventing Flight Delays Due to Unexpected Conditions

Imagining when you are trying to attend a meeting in another city and your flight is delayed. This is usually the case where scheduled pilots are absent. Air Canada Rouge is looking to build a **dynamic forecasting model to predict** *the level of pilot absenteeism[1]* so that the company can prepare an appropriate number of on-call pilots in reserve. The reserved pilots can take the place of the originally assigned pilots who are not able to fly a flight according to schedule due to unexpected conditions such as pilots' sickness etc. This prediction model can effectively decrease the delay time.

Impact

In the current airline industry, 30.2% of the total delay time is because of unexpected pilot absence.
By using the prediction, Air Canada can:
- **Increase profitability** by hiring the minimum number of pilots needed per month to minimize the labour cost;
- **Ensure the availability of reserved pilots** for replacing absent pilots when needed;
- **Improve customer satisfaction** by avoiding any inconvenience caused by flight delays.

Final Design and Key Results

To predict the level of absenteeism according to different combinations of aircraft types (319 and 767) and pilot positions (Captain[2] and First Officer[3]) per month, the team applied historical data analysis and Winter's method (a forecasting method) to design an algorithm. Four factors are used as inputs for the process of the algorithm. They are **the specific month needed to be forecasted, the type of aircraft and pilot**, and **the confidence interval**. Using Winter's method, there is an approximate **14.8%** difference between the forecasted results and the actual level of pilot absenteeism per month.

1. The level of absenteeism is measured by the percentage of total pilots absent hours to the total scheduled flying hours for each month.
2. Captain is the responsible pilot for the flight operations and safety in an aircraft.
3. First Officer is the second pilot in commercial aviation.
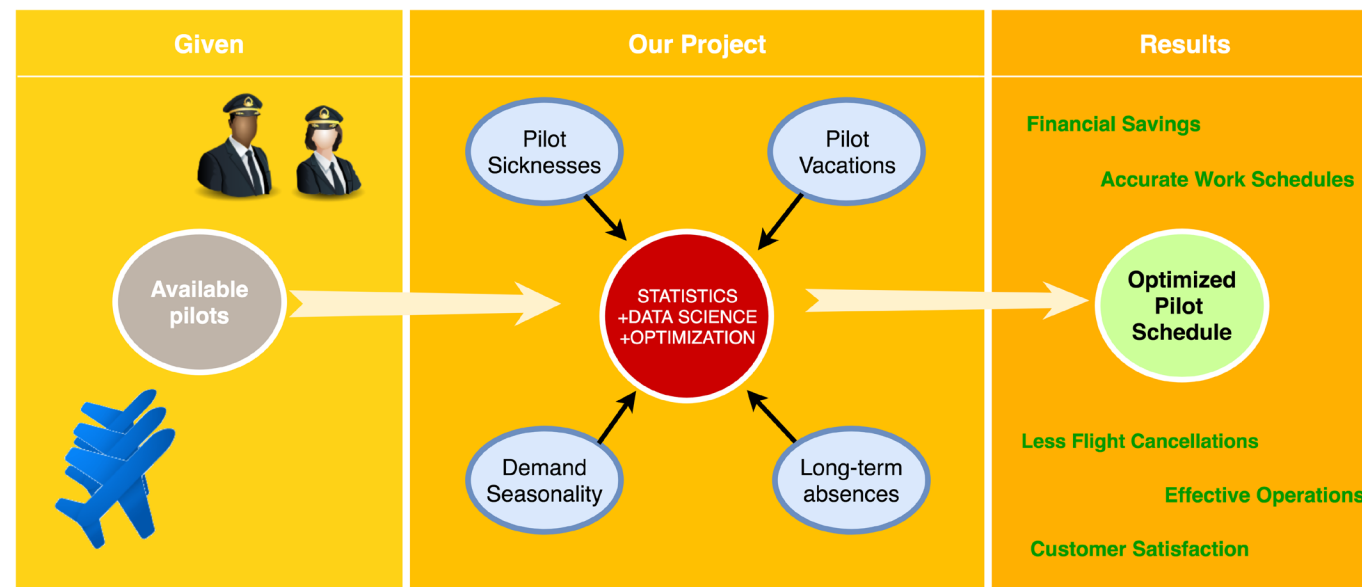
Improving Pilot Staffing through Data Science

Client: Air Canada
Team members: Mert Ersoy, Nikita Kochnev, Denis Savinov, Alibek Taizhanov
Supervisor: Daniel Frances

### Bringing Data Analytics to Human Resource Allocation

Air Canada is looking to improve the forecasting accuracy of pilot hours to be flown in a given month for the entire fleet. The forecast is used to assist pilot scheduling efforts. Air Canada already has an established process for determining the forecast and is looking for ways to reduce the variance in the current process. By increasing the accuracy of the forecast for pilot hours Air Canada will see several positive impacts.

Firstly, it will save the company money by reducing the costs associated with understaffing that is due to a forecast prediction that is lower than the demand. Conversely, it will also reduce forecasts that are higher than the demand which result in overstaffing. The cost savings include cancelled flights, overtime pay and pay for pilots sitting at home. Secondly, more accurate forecasts mean the Air Canada can more accurately match demand with supply. This results in additional pilot hours which can be used to sustain routes in peak months. Lastly, more accurate staffing would lead to reduced pilot costs which could ultimately lead to reduced prices for customers.

Overall, the impact of this will be felt by everyone from the company personnel to the customers. Customers will see potential cost reduction while the pilots will be more satisfied with less overtime requests and a more stable schedule.

Precise Staffing based on Data Clustering and Mathematical Optimization

The analysis of the current process revealed which areas were in most need of improvement. Having identified the main causes of the variance, our team applied modern machine learning solutions such as clustering to improve upon them. Mathematical optimization was used to adjust critical parameters to optimal values based on past data. In this way, crucial business intelligence from historical performance was extracted and used for precise pilot staffing at the leading national air carrier.
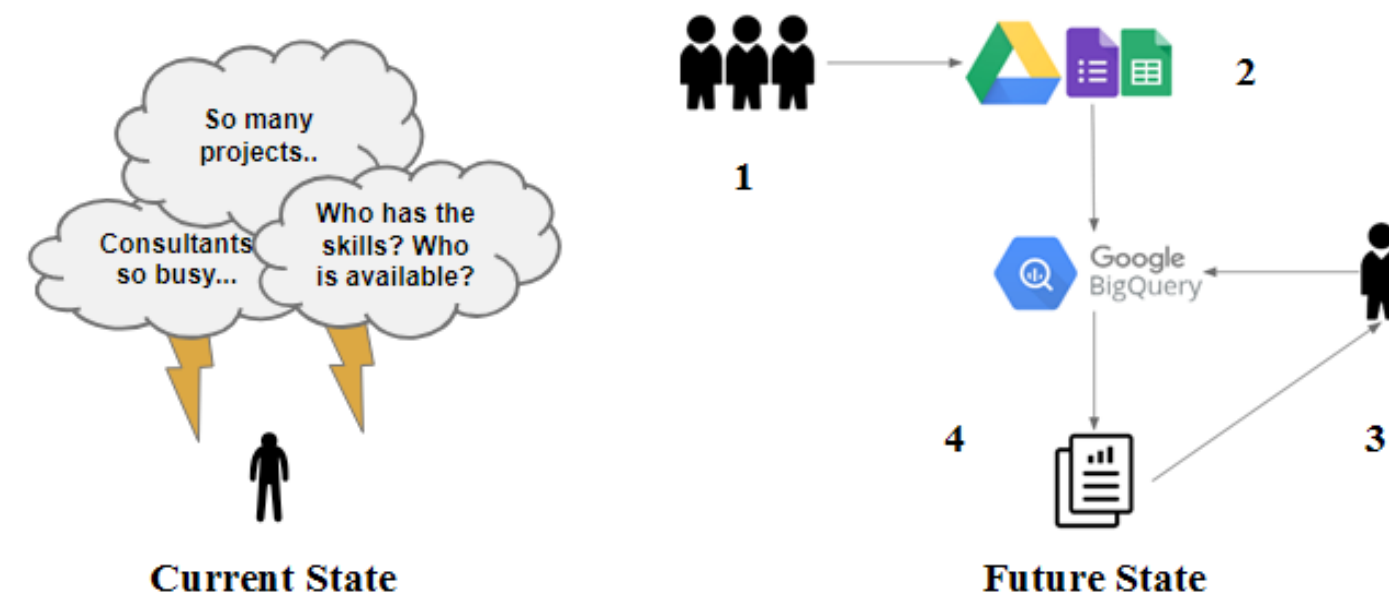
Resource Management & Process Optimization for Boutique Consulting Firm

Client: The Poirier Group
Team Members: Linda Leung, Selin Maden, Emma Sexton
Supervisor: Christopher Beck

Client Need & Impact - Scheduling Consultants to Client Projects

The Poirier Group (TPG) is a boutique consulting firm based in Toronto, Ontario, that specializes in delivering process and performance improvements to their clients. Due to their rapid and continuing growth, they are in need of a resource management system to keep track of employee information and incoming projects. Furthermore, they need a documented and automated process to schedule consultants to projects to reduce a workload bottleneck.

Providing a solution to this problem will allow TPG to expand with accurate data tracking and avoid pitfalls of having poor data management. This project will also empower more employees to complete the consultant scheduling task- where currently only one person is able to do this. This means that they are protected against changes in the team. Additionally, having the process streamlined and automated will reduce the man hours needed to perform this task and allow consultants to focus more of their time on client projects.

Overview of Design & Key Results - BigQuery Database Development and Integration

In order to streamline the consultant scheduling process, we designed a database as the beginnings of a full-fledged HRM system. This system was built in Google BigQuery to easily integrate into TPG's existing Google Drive. We then designed queries and reports that mimic the manual process of matching a consultant to a client facing project. The process can be seen in the future state figure and is as follows:
1. Employees enter billed hours and project experiences into google forms and sheets.
2. Information from the forms and sheets is pushed to BigQuery and the database is updated automatically.
3. A managing consultant can enter new projects into the database and query a list of the suitable consultants for the project.
4. The results are outputted and the managing consultant uses this information to assign the project and then updates the database accordingly.

Information Systems and Data Analytics
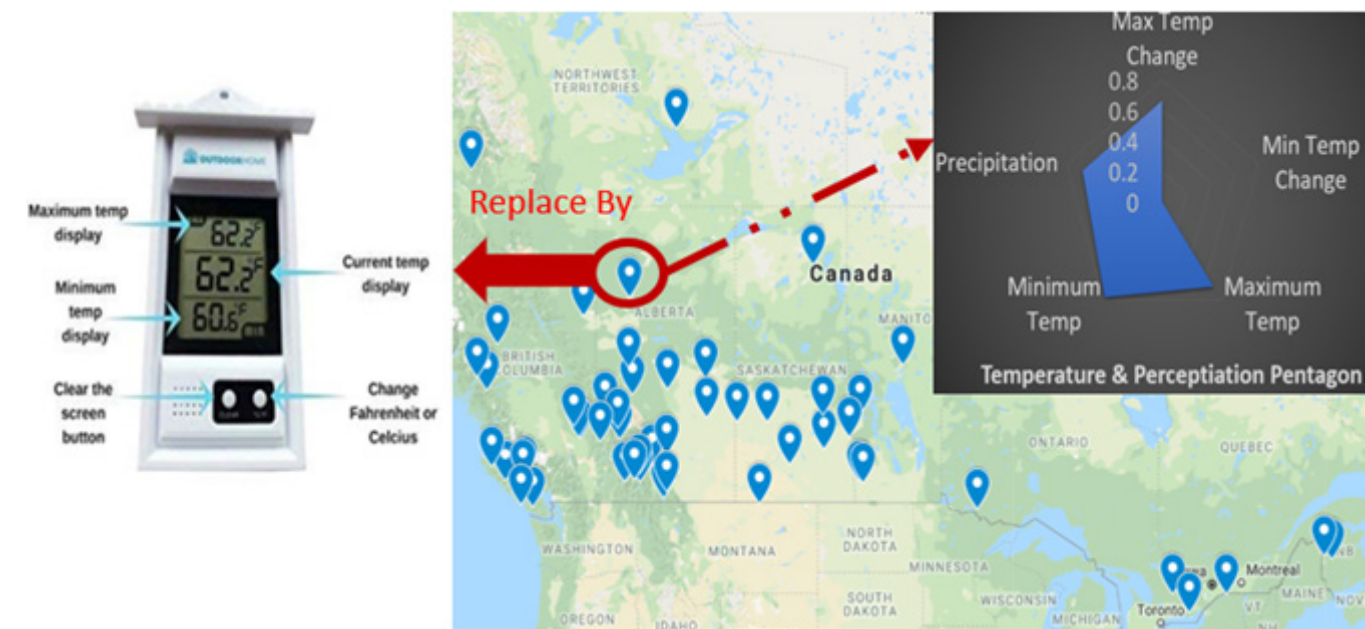
Decision Support System for Weather Stations' Operation Plan

Client: Environment and Climate Change Canada-Meteorological Service of Canada
Team Members: Linyang He, Qiuchen Sun, Ke Pan, Renjie Li
Supervisor: Viliam Makis

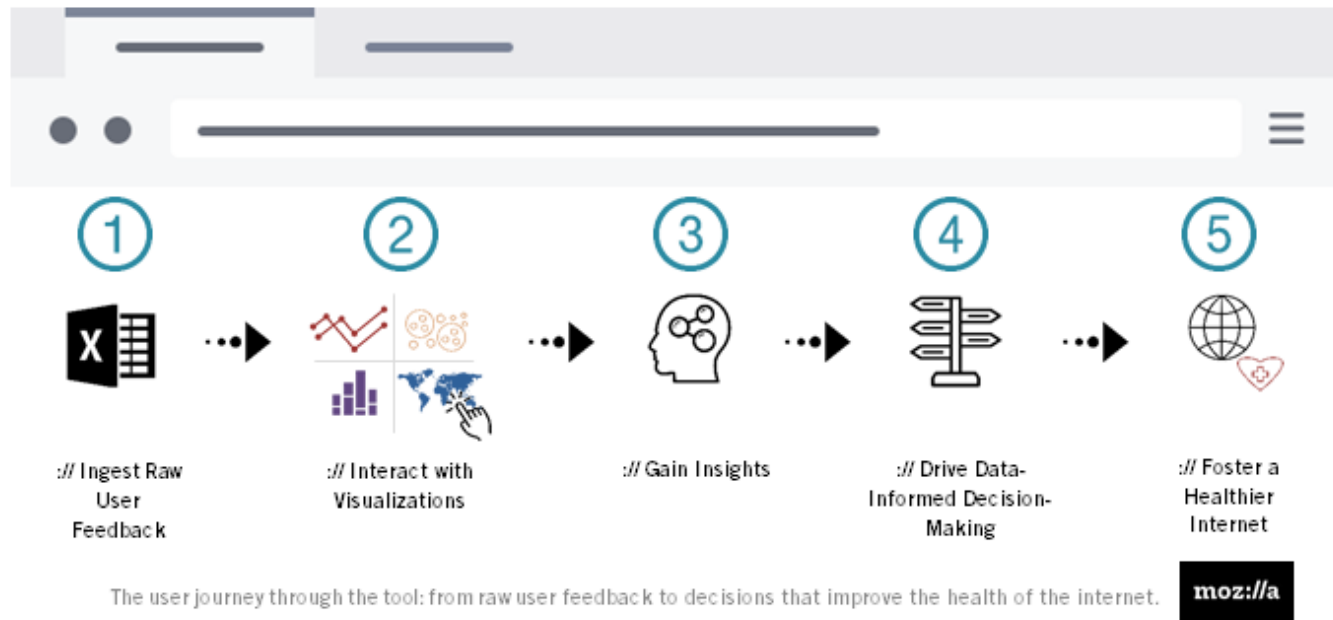### Optimizing the Stations of CCN Network

The Co-operative Climate Network (CCN) is a volunteer-run network within the Meteorological Service of Canada (MSC) branch at Environment and Climate Change Canada (ECCC), which aims to provide Canadians with up-to-date information about the past weather data and an official record of past conditions. The network is facing multiple challenges including the lack of recruitment, reduction in budget and the need to phase out current Mercury thermometers by 2020.

ECCC-MSC requires an informative framework to aid decisions on whether to shut down or upgrade the stations by more cost-effective and sustainable approaches. The primary objectives are sustainability, maintainability, and effectiveness.

The final system would help MSC optimize and modernize the weather stations using machine learning techniques, with the choice of cost-efficient equipment. By implementing the system, the CCN network can be operated with a lower budget. On a broader scale, valuable weather data can continue being provided to the researchers and environmentalists for climate change studies. Moreover, by replacing the mercury-based thermometers, the weather stations will become environmental-friendly.

The Use of Pentagon Model and Clustering Method

The design process started with evaluating the importance of weather stations by analyzing the weather patterns in the form of pentagon models. The use of a machine learning method helped make a major decision for each station. The optimal result shows that a total of sixty-five stations are clustered into three groups scoring differently in the pentagon model we designed. Twenty-two stations which scored poorly are suggested to be shut down. Six stations who scored best are recommended to be replaced by advanced automatic weather stations, and the rest thirty-seven stations will be kept and the thermometers will be replaced with the electronic ones.

The user journey through the tool: from raw user feedback to decisions that improve the health of the internet. moz://a

Decoding Web Compatibility Feedback with Intelligence and Ease

Client: Mozilla Corporation
Team Members: Bing Ning (Emily) Xu, Nicole Wongsoo, Carol Yeung, Amrit Prasad
Supervisor: Scott Sanner

Harnessing Raw User Feedback to Fulfill Mozilla's Pledge for a Healthy Internet

As part of the Mozilla Manifesto Addendum[1], the internet is the most powerful communication and collaboration resource that embodies some of humanity's deepest hopes for human progress.

Every year, Mozilla receives large volumes of feedback data from users across the world pertaining to its product lines, namely, the Firefox web browser. However, there is little to no effort spared to insightful user feedback analysis and reporting throughout the organization, especially for the Web Compatibility team (the client). The client aims to improve the web browser experience for an internet that catalyzes collaboration among diverse communities who work together for the common good. They require a process to extract aggregate and low-level insights/issues from untapped Firefox web compatibility user feedback for top websites. The solution must be robust, intelligent, scalable, and efficient for high ease of use and maintainability, to dramatically improve the user experience in the 76 locales the browser supports, globally impacting 250 million users per month.
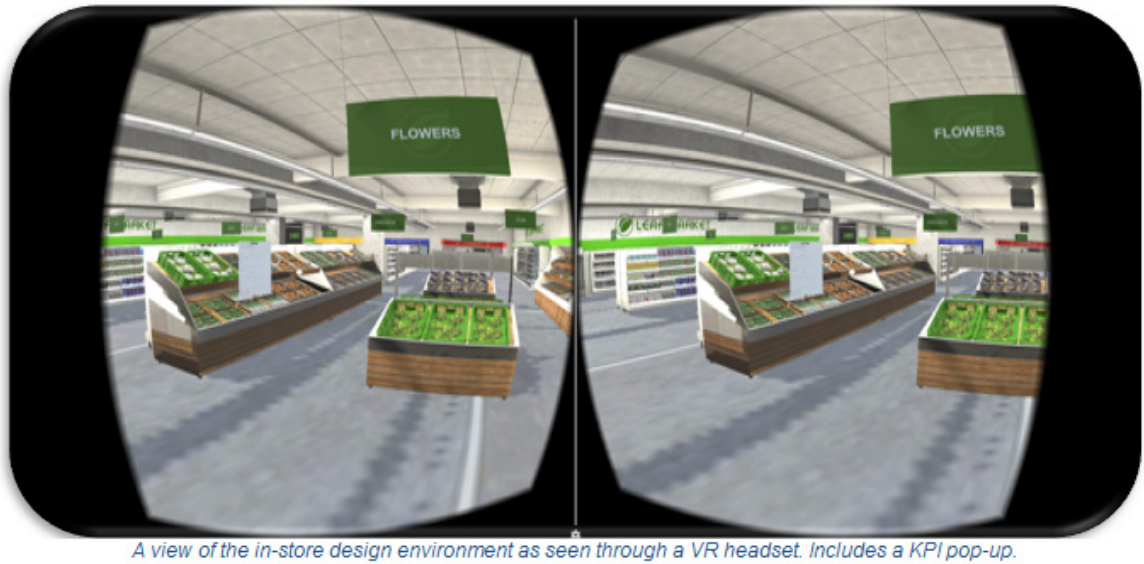
The End-to-End and High-Performing Raw Feedback Analytics Web Application

This analytics tool is a one stop shop featuring: i) data pre-processing (i.e., spam removal, natural language processing); ii) supervised and unsupervised machine learning; iii) intuitive and meaningful visualizations, and reporting formats. Leveraging Python's cutting edge interactive Dash framework, the user can, in < 12 clicks:
- View which top websites are underperforming with the browser and the root cause(s);
- Learn of new issues that have not been previously discovered;
- Discover aggregate trends regarding user sentiment or geographies; OR
- Query and download the raw feedback for further analysis.

Business Impact: 700%+ more time efficient & $600+ in cost savings (per week)
Usability/System Performance: 90.1 score on System Usability Scale (SUS), > 95% Task Completion Rate, process ~100,000 points of freeform text feedback in < 1 minute

[1]Corporation, M. (2019). The Mozilla Manifesto. [online] Mozilla. Available at: https://www.mozilla.org/en-US/about/manifesto/ [Accessed 13 Mar. 2019].

A view of the in-store design environment as seen through a VR headset. Includes a KPI pop-up.

Enhancing Retail Data Visualization with Virtual Reality Technology

Client: LoyaltyOne
Team Members: Calvin Lo and John Browne
Supervisor: Mariano Consens

The Potential Impact of VR Technology on Modern Retail Businesses

Virtual Reality is an exciting emerging technology, but its application to the business world remains largely unexplored. In an ongoing effort to provide customers with the most innovative products possible, LoyaltyOne tasked the Design Team with exploring the ability of VR to improve on traditional methods of retail data visualization. The resulting product has the potential to change the way organizations present and interpret data, making information much more natural and intuitive. Rather than relying on traditional dashboards and charts, our design allows decision-makers to view data in an environment that closely replicates the actual in-store experience. Contextualizing the data in this interactive manner increases retention and makes it easier to use common retail metrics to inform real-life decisions.

The Virtual Store: How and Why it Works

Putting on the VR headset, the user enters a 3D model of a retail store. The user can change camera angles using head movements and move around the store using an external control. Walking around the store, the user can select specific products on the shelf to activate a pop-up that presents KPIs and graphs on basic retail data. The user can additionally activate a heat map, which shows the products or areas of the store that are most popular amongst customers. At the rear of the store, the user can enter the Data Visualization Centre, which displays metrics related to the store's overall performance as well as a miniature 3D model of the store showing either location-based revenue statistics or information regarding the shopping habits of customers based on the other items in their cart. Our product is unique from non-VR based products in that it facilitates a totally immersive data visualization experience that ties retail metrics to both products and in-store locations. In doing so, our product enables immediate and impactful contextualization of data for more effective decision making.
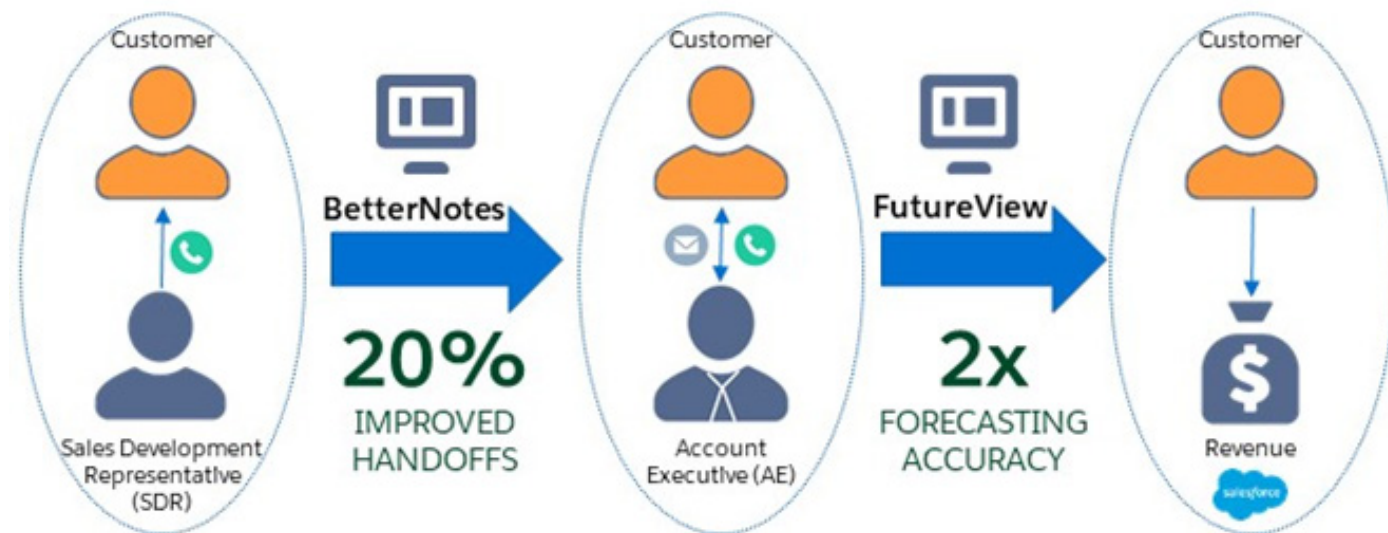
Smarter Sales – Boosting Forecasting and Handoffs At Salesforce

Client: Salesforce
Team Members: MohammedShabbar Manek, Ilya Kreynin, Ronen Yakubov, Rohit Zachariah
Supervisor: Timothy Chan

Salesforce Needed Better Communication and a Clearer View of Future Sales

Salesforce AMER SDR consists of 200+ sales development representatives (SDRs) across 6 cities, each making 60+ calls a day to source potential customers (leads) for Salesforce, a prominent business-facing software company. AMER SDR tasked the team with improving forecasting and progression of sales. Forecasting monthly sales was a manual, high-level and inaccurate process – this presented a clear opportunity for improvement. The team also discovered a need to improve the handoff of leads from SDRs to Account Executives (AEs), whose job is to complete the sale – the more handoffs are successful, the more revenue AMER SDR generates.

Two Software Solutions - Tools To Combine Data Insights And Human Insights

BetterNotes: After analyzing handoff notes from over 70,000 past deals, the team discovered the key factors that influence handoff success. These insights were proven in a 3 week, 20 SDR live study across Atlanta and Chicago, and informed the design of BetterNotes, a new interface that improves SDR and AE experience and performance.

FutureView: The team trained a novel machine learning model on years of sales data, teaching it to predict sales. This model became the brains behind FutureView, a software tool the team developed and tested with SDR leadership in Toronto and San Francisco. FutureView provides automated, live sales forecasting via a unique "Likelihood To Close" score for each sales lead active within AMER SDR, enabling rapid analysis and problem solving.

Scalable Improvement In Forecasting And Customer Handoffs

Forecasting improved dramatically, becoming 2x as accurate, greatly increasing granularity, and automating a tedious manual process. Handoff success rates improved by 20%, leading to projected sales increases of over $10 million, and the new interface will improve the daily working lives of 200+ SD
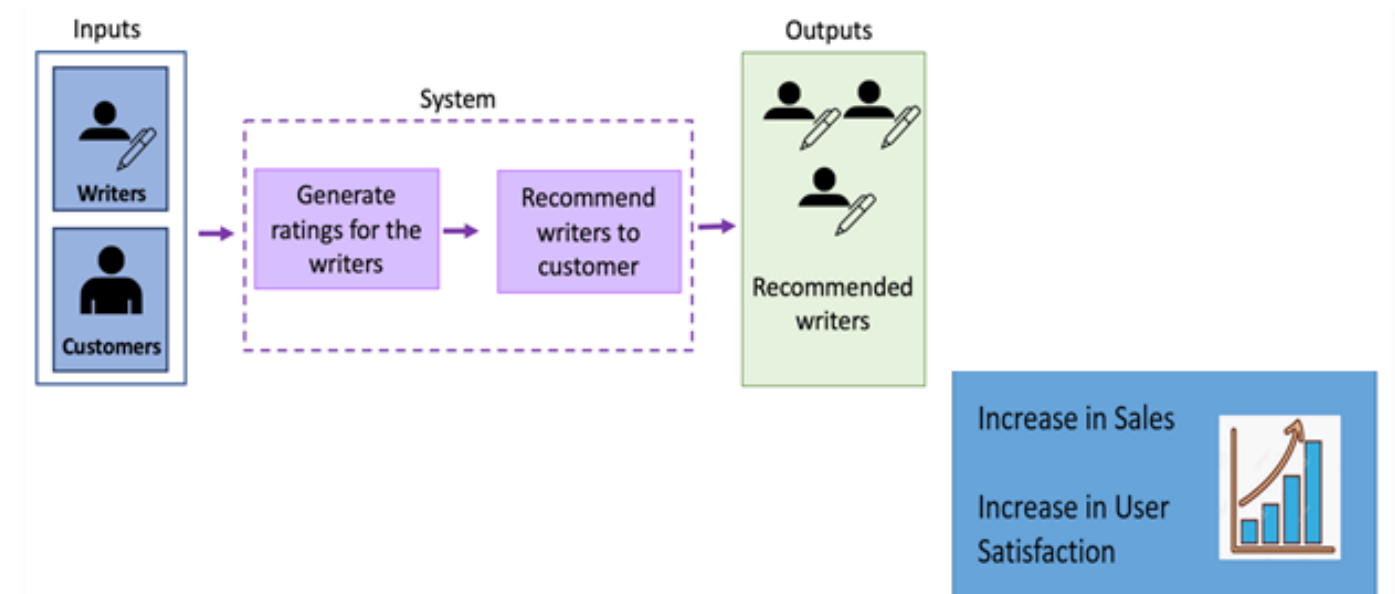
Top 10 Picks – ContentFly's Future Platform

Client: ContentFly
Team members: Ahnaf Abid Hassan, Houman Madani, Hin Wong
Supervisor: Mariano P. Consens

Client's Background
ContentFly is an online platform for matching freelance writers with customers. Customers use it to delegate writing (such as blog posts, articles) to a writer.

Project description and Objective
Currently, their matching process is done manually which is time-consuming, and requires employees to ensure smooth operations. The growing demand for their platform is increasing workload and overwhelming their employees. Their vision for the future is to increase the quality of the matches and have an automated matching process to save time and resources. This automation improves the matches, satisfies the users, and accommodates the growing demand.

Engineering Design Process and Final Design
The proposed solution for ContentFly is a recommender system. The designed system takes customer ratings of all the writers as an input and outputs a list of top writers for a specific customer. The system has two phases. The first phase is to predict the rating for the writers that a specific customer has never worked with. The second phase is to generate a list of the top writers for the customer, based on the predicted ratings. After the second phase, the customer can be matched with any of the top writers.

Overall Impact
Using a recommendation system will provide ContentFly with the same performance benefits as other large-scale companies, such as Netflix and Facebook. Reducing human input from company staff and customers will attract more users and increase satisfaction. By automating the system, ContentFly can be competitive with other online freelance writing companies in the fast-growing tech industry. This recommender system will be used to accelerate the matching process and lead to more user satisfaction.

Future Steps
In future iterations, ContentFly can modify the system for various purposes, like automatically assigning the document to the recommended writers. The platform should be integrated into the system and ContentFly should continue to improve on the system's performance based on user feedback.

Medical Equipment/Health Care Technology

Example of current Positive Airway
Pressure treatment devices
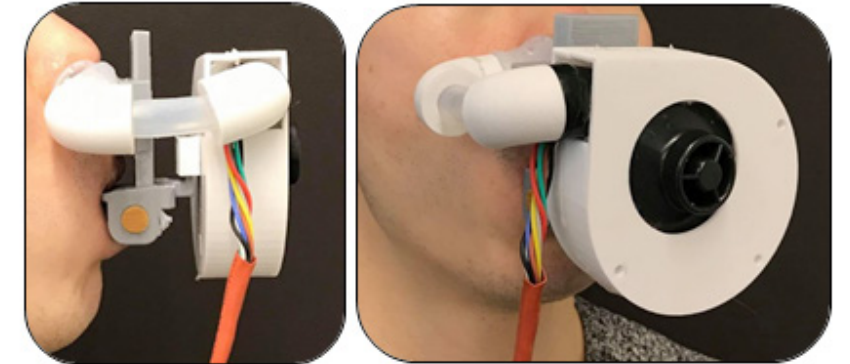
Novel Sleep Apnea treatment device

Improved Positive Airway Pressure Treatment Device for Sleep Apnea Patients

Client: Intelligent Engineering Solutions (IES)
Team Members: Shao Zhang, Soo Young Kim, Tyler Davids, Anthony Raso
Supervisor: James Mills

Issue of Non-Compliance in Patient-Administered Airway Pressure Treatment

Sleep Apnea is the medical condition where breathing frequently stops during sleep due to a collapse of the throat muscles. The common treatments for apnea are Positive Airway Pressure (PAP) devices to support the throat structure, or the use of a dental appliance which displaces the jaw to increase the throat area. While PAP is much more common due to its clinical effectiveness, around 34% of patients are non-compliant. Two ergonomic issues found on most PAP devices were identified to be major sources of non-compliance. They are:
- The straps used to secure the air respirator to the patient during sleep
- The air tubing needed to connect the air respirator to the external air generation device

### Novel Hybrid Device Combining Airway Pressure & Dental Appliance Treatments

Our design uses the dental treatment as a complement to PAP, while directly addressing the identified sources of noncompliance. Notable aspects are:
- The dental appliance acts as a rigid anchor to secure the respirator, eliminating the use of straps
- The external PAP device is moved onto the respirator assembly, eliminating much of the tubing
- The hybrid treatment reduces the extent to which each individual treatment is needed, improving overall treatment comfort

The design is validated through a comprehensive process involving computer modeling and both conceptual and detailed prototyping.
- Modeling results and sources in the research literature indicate that the required treatment positive pressure may be reduced by up to 48%
- Consultations with a respiratory medicine professional further supported the basis of the design

The novel device addresses the issues of PAP with patient convenience and usability in mind. The vision is then a device that is as seamless as brushing one's teeth before bed. Our design validates this possibility and presents a possible direction for future designs aiming to improve compliance.
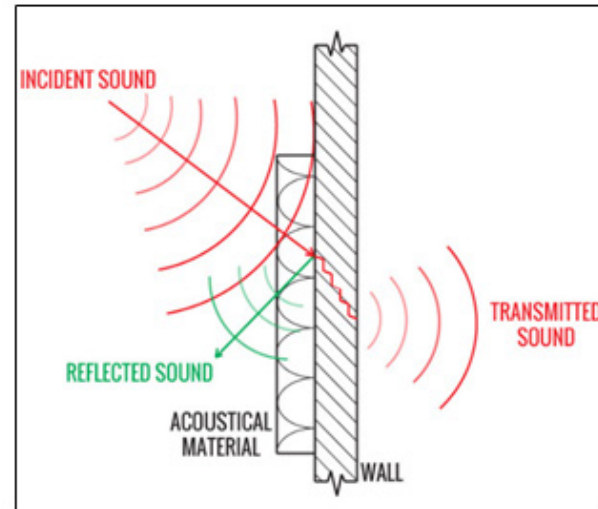
Passive Noise Control in Health-Care Environments

Team Members: Alexander Cheng, Elton Phan, Hui-Jan Lu, Jacky Pan
Supervisor: Anthony N. Sinclair

Reducing noise levels can improve patient experience

Noise, defined as unpleasant sound, is an issue in both public environments and private workspaces. The goal of health-care institutions is to provide patients required treatment, respite and an environment conducive to their recovery. However, excessive noise has a negative impact on patient sleep and their recovery process. There is a need for a solution that improves the sleeping environment for inpatients by reducing incident noise.

By rectifying this issue, we can:
• Improve the patient recovery process
• Reduce average length of inpatient stay
• Decrease stress and anxiety levels for patients and nursing staff

This is a positive step for patients, patient's families and the hospital administration. Inpatients (and their families) will know that they are in an environment that helps them heal and return to their homes. Reduced inpatient stays will save money for both the families and the hospital in the long term.

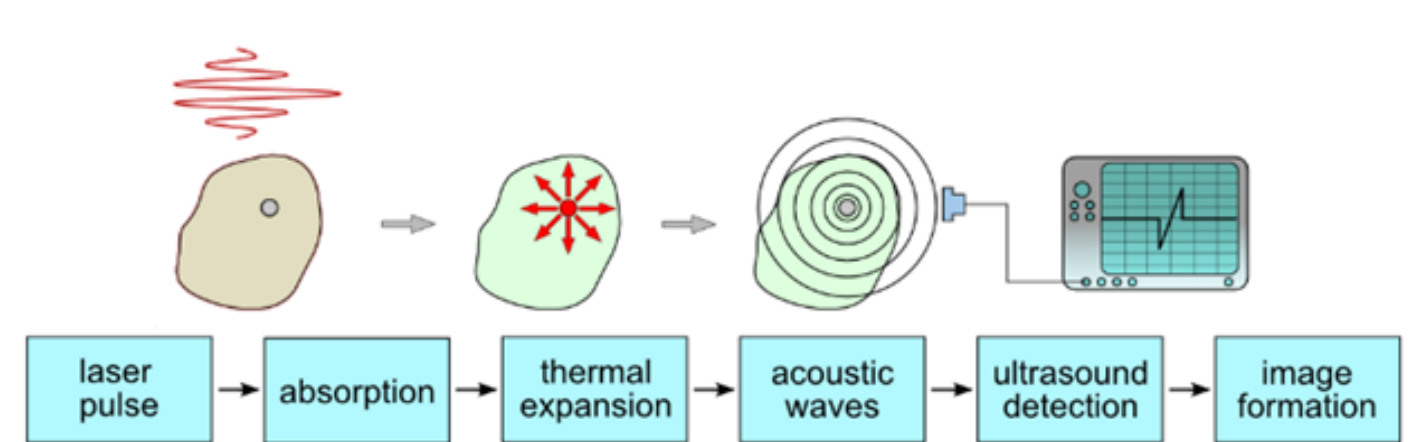### Enhancing a sleep environment with Acoustic Sound Panels

Acoustic sound panels attenuate sound levels by absorbing sound energy that strikes its surface. Adding acoustic material to a room increases the amount of sound energy that it can absorb. There are two types of panels:
• Wall panels: mounted flush on walls because the walls have low absorptive properties
• Ceiling panels: hung from the structural ceiling, both sides exposed for more absorptive surface area

Based on WHO recommendations, the solution aims to reduce noise levels to 38 dBA by using a mix of the two types of acoustic panels. To determine what acoustic panel configuration and surface area is required in each of the patient ward rooms to achieve the goal, a model was made from theoretical and empirical data.

Photograph accessed from: http://exclusive.multibriefs.com/content/help-your-patients-and-staff-by-reducing-hospital-noise/healthcare-administration
Acoustic Panel Schematic accessed from: http://www.technature.ca/acoustics-101/sound-absorption/

# Photoacoustic Imaging Catheter Design for Early-Stage Arterial Plaque Detection - Optical Source Focusing

Client: Sunnybrook Hospital and Conavi Medical
Team Members: Annie Yu, Raymond Lam, James Liu, Rhoda Gnanasegaram
Supervisor: Andreas Mandelis

A Need for Coronary Arterial Imaging

• Build-up of plaque within the coronary artery can lead to atherosclerosis (narrowing of arteries).
• Early detection of atherosclerosis is difficult as symptoms do not show until the artery is severely narrowed.
• Plaque imaging is currently detected by inserting catheter within coronary arterial walls.
• Early diagnosis of atherosclerosis through minimally invasive procedures can further determine the need for open surgery.
• The current stage of research involves testing combined photoacoustic and ultrasonic modalities.
• The outcome will be useful to cardiology surgery decision making for patients wearing coronary stents and monitoring recovery progress of patients in remote areas.
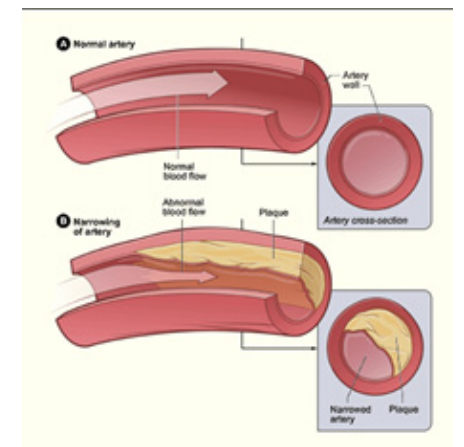
A Focus on Focus

• A low-power continuous wave (CW) optical source excites plaque for imaging from the inserted catheter. The source wavelengths have properties that help characterize plaque composition.
• A sensor (transducer) at the end of the catheter collects ultrasonic response signals from excited plaque that is used to create an image of the arterial wall.
• In the current experimental setup, the optical source is diverges outside of the optical fiber. This yields low resolution images with uncertainties in plaque location and overall composition.
• The new design has a focusing method that converges the optical source on arterial wall for improved imaging, for both wavelengths.

Silicone Drop-on-Demand (DoD) 3D Printer Project

Client: Advanced Research Laboratory for Multifunctional Lightweight Structures
Team Members: Yining Wang, Ruojing Song, Changsong Yang & Kangwei Wu
Supervisor: Kamran Behdinan

A Long-Awaited Technology: Elastomer 3D Printing
The world has witnessed many ingenious manufacturing technologies, but 3D printing has really caught everyone's attention over the past decade. The printing materials, however, have been mostly restricted to rigid materials due to the limitations of the technology. Products that can 3D print real elastomers, such as inorganic silicone rubber, are hardly available, albeit the striking benefits to prototyping and small series production of silicone products. Silicone 3D printing will open up amazing possibilities in the future and, as many believe, can be revolutionary to many fields. With this vision, our client asked our team to develop a solution to print Ultraviolet (UV) Curable Silicone materials using Drop-on-Demand (DoD) technology.

A Better World with Silicone 3D Printing
Compared to traditional manufacturing processes of silicone, 3D printing significantly reduces the production time and costs especially for prototyping small product series. Its unique process allows engineers to create products with complex structures that would be impossible to produce with traditional manufacturing methods. With 3D printing, silicone products can be designed in a better way and be more affordable to customers. The major advantage of silicone 3D printing, however, lies in individualized applications and can have a significant impact in many fields, such as medical science. Silicone 3D printing can help customize medical treatment for individual patients. For example, customized biomodels can be 3D printed to aid pre-surgical testing. Silicone implants and prostheses can now be individualized with lower costs. In a word, with silicone 3D printing, we can build a better world.

Introducing "Phoenix" Printer Kit
Our team developed the world's first silicone 3D printer add-on kit – "Phoenix". The kit can be installed on MakerBot Experimental Replicator 2X FDM 3D printer and convert it to a silicone 3D printer. The design uses a piezoelectric actuator and a ball-needle jetting configuration to realize drop-on-demand printing of silicone. The silicone is cured by a UV light source at the same time of printing. A prototype was constructed for demonstration and testing purpose.

Image Source: http://www.openbiomedical.org/how-3d-printing-is-transforming-heart-surgery/
http://www.woodlaketechnologies.com/product-p/mak130.htm

Ultraviolet Sanitizer for Portable Devices

Client: Confidential
Team Members: Chan Ho Lee, Po Ting Chou, Heechan Kang, Donghoon Kim, Putthipat Preecharwongsiri
Supervisor: Lidan You

Eradicating Infection-Causing Bacteria in All Healthcare Facilities
Each year in Canada, more than 200,000 patients are affected by Healthcare Acquired Infections (HAIs). These infections are caused by bacteria transmitted via inadequately sanitized mobile devices. Increases in technological advancements have resulted in an exponential increase in mobile devices, further intensifying problems associated with HAIs and demanding more advanced solutions tackling this important problem.

The capstone team was tasked to design a sanitizer that utilizes ultraviolet rays to eliminate pathogens as well as guiding the client through applicable standards. Once approved by the regulatory bodies, this product will be able to sanitize equipment beyond mobile devices in hospitals, thus increasing the chances of easier adoption of the technology by hospital staff and visitors. This means a reduction of HAIs, less economic burden on the healthcare industry to combat HAIs, and more lives saved.

A Novel Design - Surface Disinfection with UV-C LEDs
Our design will be one of the first products ever to utilize UV-C LEDs for surface disinfection. Traditionally, UV-C LEDs have been used in water disinfection and air purification, while current UV sanitizers make use of mercury bulbs. Not only will its use comply with future regulations against mercury toxicity, UV-C LEDs provide faster response, lower power draw, customizable wavelengths, and longer life.

We proposed over 30+ Industrial Design concepts to ensure adherence to client requirements such as intuitiveness, ease of use without training, modern medical device appearance, and alignment with company branding. A well thought-out ID ensures acceptance into healthcare spaces and promotes usage.

Our prototype is positioned between a basic proof-of-concept prototype and a fully production-ready design. It was manufactured using production-grade rapid prototyping methods. The prototype shall be used by the client for pilot studies at various hospitals to validate the business model and the go-to market strategy prior to significant investment for commercial development. A detailed road map for regulatory approval was also written, which lays a strong foundation for the client during the commercialization phase.

Process Engineering/ Decision Support Systems
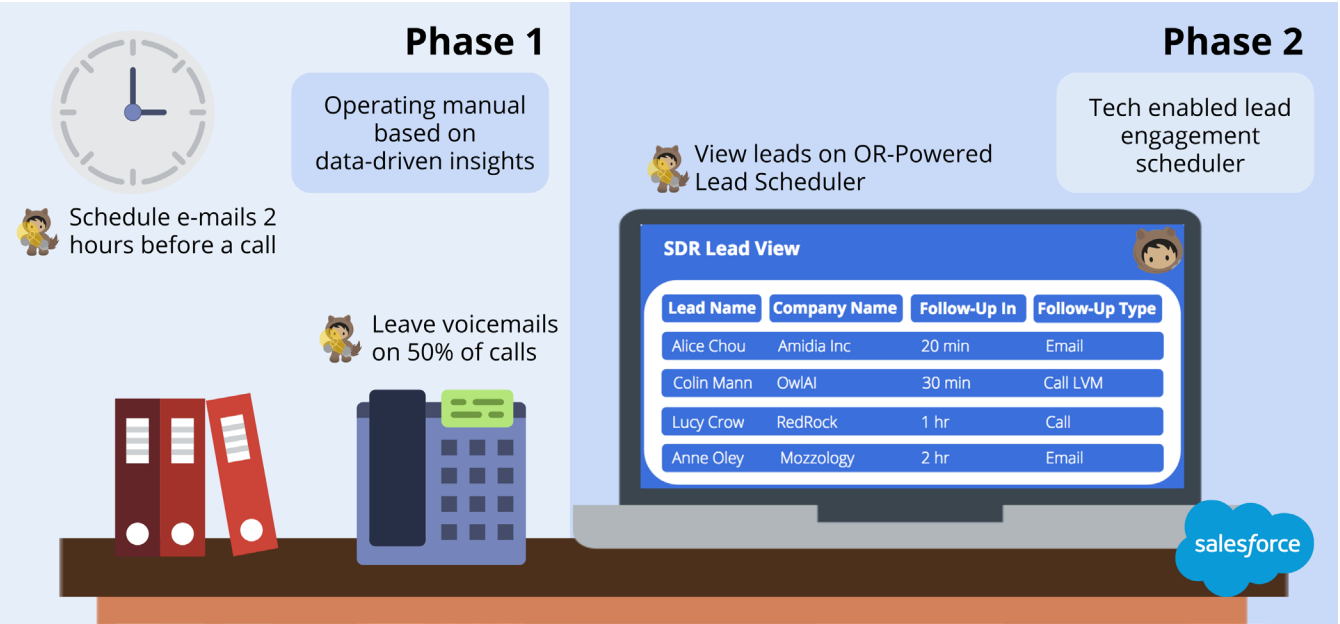
From Data to Dial: Driving Sales through the Force of Analytics

Client: Salesforce
Team Members: Lu Chen, Alison Chow, Connor Lawless, Ana Medinac
Supervisor: Timothy Chan

Leveraging Data to Drive Effective Sales

Sales is a ubiquitous but challenging process; the team leveraged millions of data points to uncover the optimal way to engage a potential customer. Salesforce, the leading customer relationship management system, contacts over 200,000 potential customers annually, but only connects with less than half.

The team objectives were to:
1. Find the best sequence of actions (email, call, call with a voicemail) for sales development representatives (SDRs) to perform in order to maximize the probability of connecting with a lead
2. Develop an interface SDRs can use to leverage the insights from Objective 1, and help each SDR manage engagement for over 150 leads per day.

Data, Optimization, and Human Factors: An Integrated Industrial Engineering Approach

The team analyzed one year of Salesforce's North American sales data with millions of lead activities using a novel pipeline created through Alation, Python, and R. The final design is:

Phase 1 Operating Model: The first phase provides data-driven best practice strategies to engage a lead, including whether to leave a voicemail and which calls should be paired with an email. A live pilot, testing insights included in the operating model, showed that Salesforce can expect an estimated **7% increase** in connect rate, translating to **US$7M annually** in additional revenue.

Phase 2 Tech Enabled Engagement Monitor: The second phase, enabled by an optimization model and a user interface, schedules each SDR's leads for the day and provides detailed guidance on the activities that should be enacted, boosting connect rate by an **additional 6%**, or **US$6M annually** in additional revenue.

Business Impact: Overall, this will impact the operating cadence for hundreds of SDRs across North America and produce an expected annual increase of over US$13M in revenue. Beyond Salesforce, these insights are applicable to the US$400B cloud computing industry, and more broadly sales across North America.
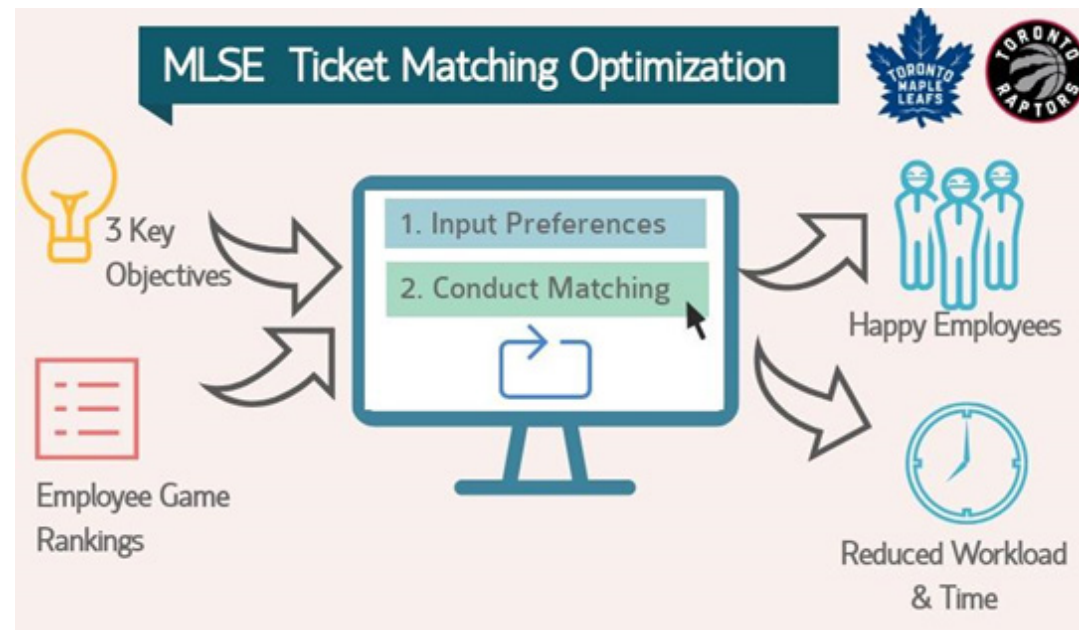
Unlucky? Not With Ticket Matching Optimization!

Client: Maple Leaf Sports and Entertainment (MLSE)
Team Members: Aidan Jappy, Alex Walmsley, Sookyung Kim, Yeajin Lee
Supervisor: Timothy Chan

Automated Matching for Equitable Ticket Matches

MLSE sought an automated method for matching complementary Leafs and Raptors tickets to their employees. Employees can rank and submit their top three choices - who doesn't want free tickets? However, there's a catch! Each game has a limited number of tickets available, thus presenting a classic one-sided matching problem, like matching organ donors to recipients. Our goal was to develop a matching model that reduced the administrator's manual workload and ensuring that employees receive fair matches.

How is fairness measured and how can it be mathematically incorporated into an automated matching model? Having to address this philosophical predicament was the core challenge of the capstone project and is commonly encountered in other industries as well. The solution we developed could benefit any organization struggling to determine who deserves to get what. Ultimately, the solution transforms roulette luck into equitable results, leading to happier recipients.

The Solution: An Optimized Matching Model + Interface

The developed matching model incorporates three key objectives that were identified through user research with MLSE employees and are shown below. The matching model iteratively generates 'match' solutions that balance the three objectives according to employees' definition of fair matching.
1. Minimize the number of non-matched employees
2. Maximize the number of employees matched to their first-ranked game
3. Minimize the number of "unlucky" employees - those who receive poor consecutive matches

The robustness of the matching model allows for a high degree of flexibility to accommodate the many subjective measures of fairness. By producing optimal matches, backed by employee focus groups, we were able to reflect the organization's ethical disposition and align to what employees deem as "fair".

Retail/Supply Chain Management

Error Before / Error After: 13.2% → 7.7%

Future Opportunity / Expected Savings: $2.1M/year, $7.9M/year
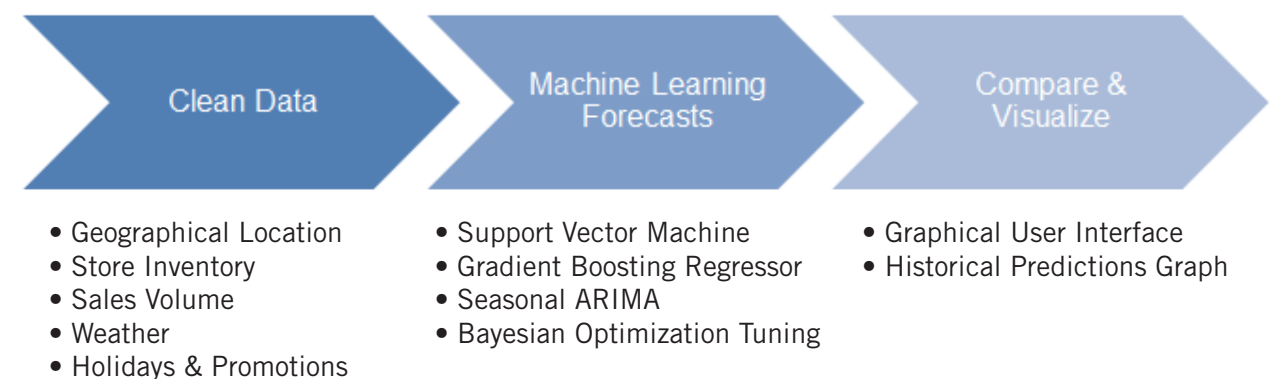
Machine Learning for Global Supply Chain Forecasts

Client: Canadian Tire Corporation (CTC)
Team Members: Nicholas Jalen Cheng, Alex Kwan, Victor Lo, and Jiming (Edward) Zhou
Supervisor: Chi-Guhn Lee

### Reducing Forecasting Error Within Distribution Centres

- CTC has 500+ Canadian Tire retail stores and operates the country's largest retail supply chain
- CTC's distribution centre forecasts for non-promotional demand are currently a simple average of previous years' volume
- More precise distribution centre forecasts can be obtained using 2013-18 CTC data and powerful machine learning algorithms
- The Capstone team delivered a software solution with the following functionality:

Clean Data → Machine Learning Forecasts → Compare & Visualize

- Geographical Location
- Store Inventory
- Sales Volume
- Weather
- Holidays & Promotions

- Support Vector Machine
- Gradient Boosting Regressor
- Seasonal ARIMA
- Bayesian Optimization Tuning

- Graphical User Interface
- Historical Predictions Graph

A Leaner and More Reactive Global Supply Chain

- 5.5% average error reduction for weekly forecasts over 2017-18, leading to $2.1M annual savings
- Tremendous opportunity for re-investment of savings to increase shareholder returns and contribute to CTC's Jumpstart charity allowing children to participate in organized sports

Robotics/
Mechatronics/
Electrical
Technology
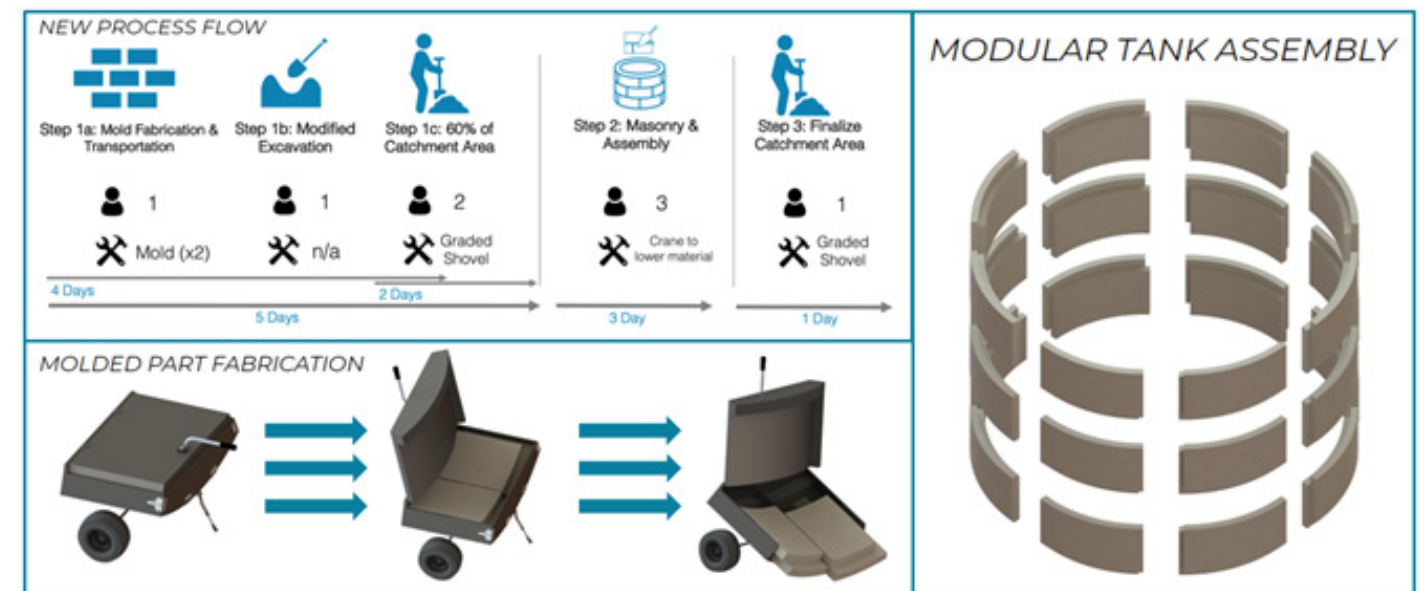
Desert to Oasis - Rainwater-Harvesting Tank Optimized

Client: One Prosper International
Team Members: Shahem Al Korani, Mouness Akour, Abdullah Mohammed, Abdelrahman Said
Supervisor: Javad Mostaghimi

Empowering More Thar Desert Residents with Access to Clean Water
OneProsper, a non-profit with rainwater-harvesting-tank (Taanka) building initiatives in the Indian Thar Desert, aims to expand their throughput by reducing the cost (from $500) and time needed (from 17 days) to build a Taanka with 20,000L capacity.

Taankas provide families with an ever-present clean source of water, thus eliminating the prior need for women and young children to walk long distances to collect water. Increasing throughput will enable more Taankas to be constructed more quickly and thus reach more residents in need.

With a source of water available, underprivileged families will be able to devote more time to the pursuit of education and development of their children, and aim to break the poverty cycle. The Taanka solution can be expanded to serve other underprivileged and arid areas, where rainfall is limited and the need for a water storage system is paramount.

Redesigning Taanka. Streamlining Process. Maintaining Tradition
Our solution comprises of three parts: a design improvement, a process improvement, and incorporation of 3 tailored tools. This approach enabled a 47%-time reduction and 18%-cost reduction, thereby meeting the client's goals.

The Taanka was redesigned to minimize the previous heavy need for specialized labor (masonry) and allow for modular construction by breaking the tank up into 24 easily stackable, assemblable, and moldable main parts. Each part can be made on site or in advance by filling a custom mold with a custom concrete mix, before it is lowered into the excavated hole and assembled part by part.

The process was refined to eliminate idle time and incorporate tools to more efficiently complete tasks. Catchment area (surrounding inclined area around tank) preparation and hole excavation are now done simultaneously and implement the use of a graded shovel, and the molded parts are safely lowered using a designed pulley system. Prototype testing of the mold and various cement mixes were performed to confirm ease of manufacturability and quality of build. By implementing the three aspects of the design, OneProsper will achieve their goal of expanding their operations and providing more families with access to clean water.

Modular Dielectric Test Fixture
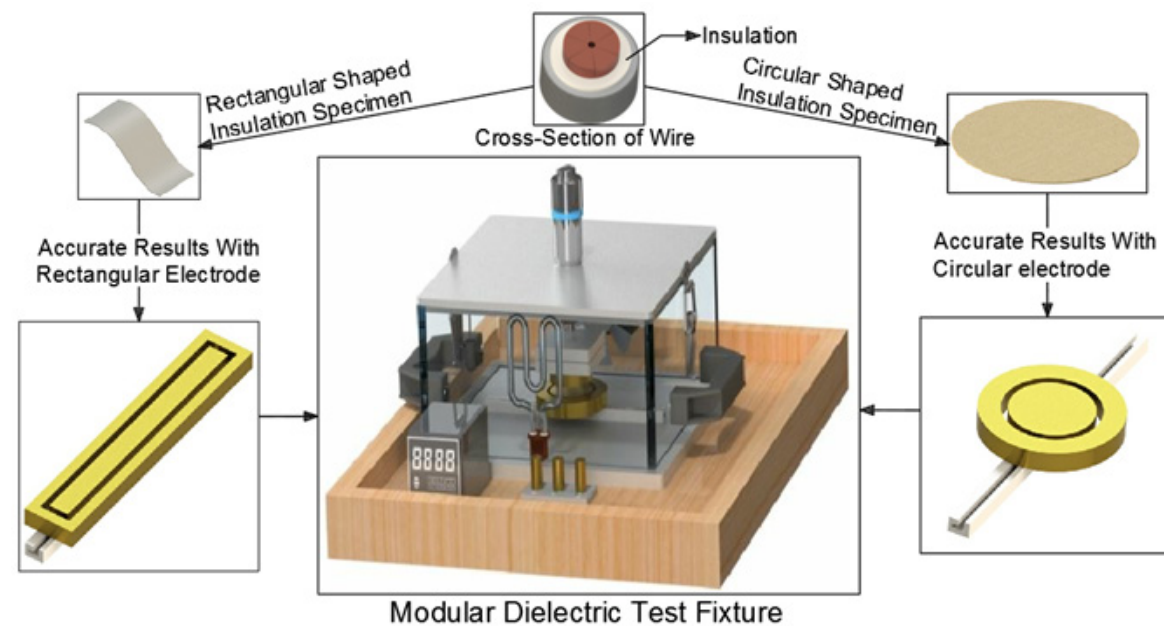
One Fixture for All Dielectric Test

Client: Kinectrics Inc.
Team members: Rounaq Jahan, M. Fahad Uddin, Hassan Zareef, Joshua Bakhsh
Supervisor: Alison Olechowski

Wires Age Just Like Us!

Electrics cause 80% of fires in residential buildings and factories. These fires often result from arc faults which occur when high-voltage current exits a wire's conducting core through damaged insulation. Since electrical insulation is prone to wear with age, it should be routinely tested to assess its quality.

Size Matters, So Does Shape

Electrical wires come in various shapes and sizes with different insulating materials depending on their functionality. Common insulators in cables and transformers are oil-impregnated paper and cross-linked polyethylene. The insulation specimen varies in geometry depending on the type of insulation being tested. The fixture for the dielectric test comprises of electrodes that houses the specimen in between. These electrodes must match both the shape and the size of the specimen for higher accuracy of test. However, existing devices such as the Samgor RY2 can accommodate only one electrode geometry. Another existing device, the Keysight 16451B, accommodates different sizes of electrodes but not shapes. Using these devices as a benchmark, our design aimed to create a modular device that can work as a one-fixture-for-all testing.
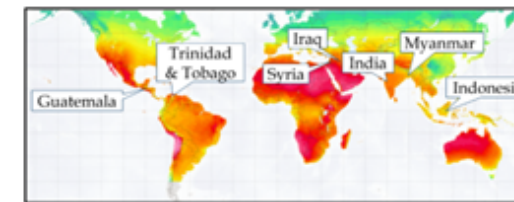
Our Approach to Modular Design

The fixture was designed to comply with the standards of ASTM D150 and to safely operate in voltages up to 2000V. The distinguishing features of the design include:

- Comprehensive adapter and base mount that can house different geometries of electrodes
- The specimen can be heated up to 150°C
- Integrated PID controller can maintain the temperature at a desired set point
- Manual pressure control with a micrometer head and an integrated pressure sensor
- Very low cost of material at only $150

PowerResponse: Using Renewable Energy in Disaster Response

Client: GlobalMedic
Team Members: Albert Liu & Erica Voss
Supervisor: Li Shu

Powering the AquaResponse

GlobalMedic provides emergency response to communities affected by natural disasters and crises. A key aspect of their support is providing safe drinking water to the communities affected using a pumped water filtration device called the AquaResponse. Currently, the AquaResponse unit is powered by a running vehicle, which consumes large amounts of fuel and limits the types of communities where it can be deployed.

GlobalMedic is seeking a reliable power source that is:

- Highly portable
- Durable
- Easy to maintain
- Cost effective

Our Solution

The team evaluated three modes of power generation - solar, thermal, and human - to see what would fulfill the above criteria in the highly variable service environment that GlobalMedic experiences. It was determined that no single mode would provide reliable power in all environments. Therefore, all three modes were combined into a modular solution. The three modules are linked by a deployment plan that identifies the ideal combination and size for the geographical location and type of disaster.

Impact

By providing GlobalMedic with portable, reliable power, they are able to more effectively plan their emergency response. The concept of the modular approach allows for easy scalability to match the power demands of various AquaResponse units and allows GlobalMedic to adapt their use of the AquaResponse unit for every service environment. Additionally, by improving the portability of the power source and removing the reliance on a vehicle, GlobalMedic will be able to access more remote areas to provide safe drinking water.

Revolutionizing Fume Hood Testing

Client: UofT Facilities and Services Department, Mr. Paul Leitch
Team Members: Sourabh Das, Nathan Wan-nap Luk, Eric Wai-Kit Wong
Supervisor: Sanjeev Chandra

Ensuring the safety of our students while keeping the cost down

A typical older fume hood can have 3.5 times the energy use of an average household over a year. At UofT, lab buildings are some of the highest energy use buildings per square foot. With the rising demand to adopt new high efficiency fume hoods, the current standards for fume hood safety evaluation are time-consuming, expensive, require highly specialized equipment, and unable to accurately evaluate high efficiency hoods.

The UofT Facilities and Services Department and Health and Environmental Services Department have collaborated to develop a new system to more thoroughly evaluate fume hood safety and functionality by detecting escaping gases across the sash surface via a laser sheet and a smoke-generator.

This final configuration can decrease operation time by a factor of 3 and reduce cost by over a factor of 10 from current testing methods. The team focused on video analysis of the system in use, and redesign of the system rig. The developed video processor written in Matlab was optimized to reduce analysis time while retaining accuracy. We demonstrated that any low end camera with a recording speed of 6 FPS and a resolution of 480p could capture all the salient information seen in a better high speed camera. A laser holding rig was created to minimize setup time, maintain alignment and angular limitations.

The bigger picture

At this stage, this project provides a complete toolkit for trained professionals to conduct the test, from setup to analysis. With further refinements such as more precisely defining camera placement, this will allow the University of Toronto to maintain and retrofit their arsenal of 1500 fume hoods currently in use, as well as compete with current standards as the testing methodology of choice to keep labs around the world more sustainable and safe.
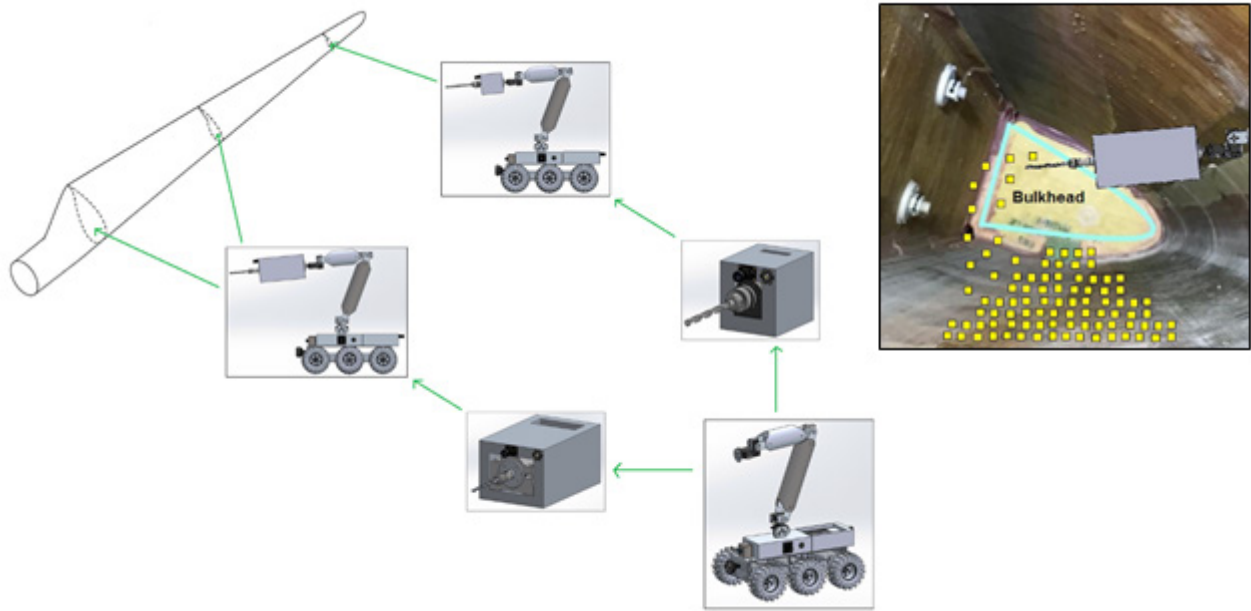
Robot Design for Removing Bulkheads in Wind Turbine Blades

Client: Borealis Wind
Team Members: Zhanling Huang, Dayu Kuan, & Frank Wen
Supervisor: Kamran Behdinan

Project Requirements & Impact on Industry

- Design a robot that can carry and deploy a tool for removing bulkheads inside wind turbine blades
- Entire assembled robot must fit through a 50cm diameter circular entrance and weigh less than 31.75 kg
- Robot must be capable of cutting bulkheads in narrow spaces as small as 114mm high and 178mm wide
- Dimensions of robot's components should not exceed 400mm × 400mm × 300mm
- Robot must travel more than 60m per battery charge and provide visual feedback from a distance of 30m
- Implement commands and complete assignments without the assistance of humans or other robots
- A successful robot design allows a de-icing system to be installed inside wind turbine blades
- Offers long-term financial benefits for owners of wind turbines located in cold regions
- Project demonstrates the usefulness of robots performing tasks in spaces too small for humans

Overview of Proposed Robot Design & Project Outcome

- Robot primarily incorporates commercially available parts
- Design process begins with selecting a suitable tool, followed by developing a robotic arm
- Final step is to create a maneuverable chassis that can support the weight of both components
- Proposed design has a robotic arm with five degrees-of-freedom & is mounted onto a six-wheel chassis
- Two interchangeable drill tool modules can be attached to the robotic arm
- Each tool module is designed for operating in a space of specific size
- Robot operator will implement a specially devised cutting procedure similar to a milling machine
- Bulkhead trimmings are tiny enough for extraction by robot vacuum cleaner
- Almost 90.3% of the smallest bulkhead can be cut out while 96.2% of largest bulkhead can be trimmed
- Stress analysis reveals robotic arm has max lift capacity of 1.5kg while chassis can support up to 8.0 kg

Bulkhead Picture Reference: Borealis Wind. (2019, January). Close-Up of Bulkhead. Kitchener, Ontario.
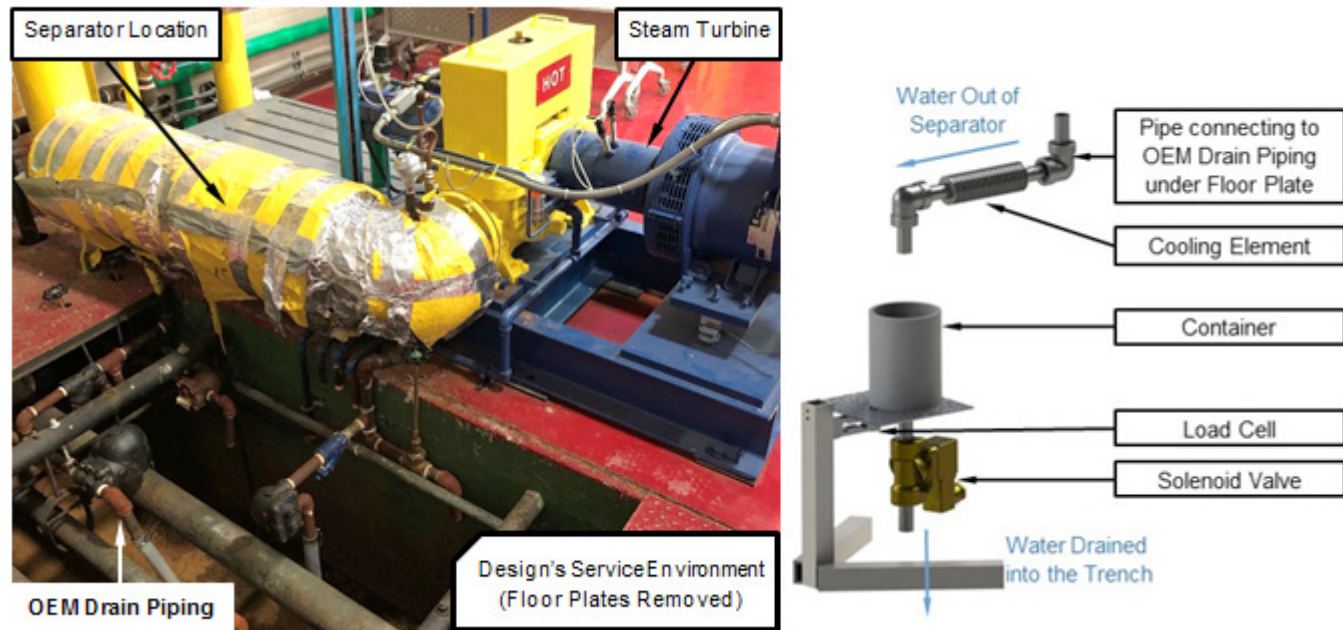
Steam Quality Measuring System for MIE Undergraduate Labs

Client: MIE Undergraduate Energy Laboratory
Team Members: Yuting Liu, Tianli Zhang, Sirui Zhu, Chao Zhao
Supervisor: James S. Wallace

Lack of Steam Quality Measuring Apparatus for Low Pressure Applications

Steam quality is a crucial parameter for determining the performance and operating characteristics of a steam turbine. Currently, the U of T MIE Undergraduate Energy Laboratory does not possess an apparatus that can measure the steam quality at the outlet of the steam turbine.

The goal of the project is to design a customized apparatus that can accurately measure and digitally display steam quality results. The design solution allows MIE311 and MIE303 lab students to correctly determine the turbine performance characteristics and provides them with a better understanding of the steam turbine operation process.

Utilize the Working Principle of a Separating Calorimeter

Steam quality is defined as the mass fraction of steam divided by the mass of total saturated mixture. A separating calorimeter is designed based on this concept, however, instead of using the mass fraction, it utilizes mass flow rates for the steam quality calculation. The team proposed an idea of determining steam quality based on the working principles of a separating calorimeter, which requires the measurement of liquid flow rate at the end of the separator. A steam turbine test was established as a proof of concept. During the test, the amount of water drained from the separator was measured. Several trials with 3-minute intervals were performed under the same loading condition. The test result shows that the amount of water drained was consistent. Therefore, the team concluded that determining steam quality using the separator was a valid solution.

The next step is to design a system which can measure weight and convert weight into flow rate. A load cell is used to measure the weight of liquid water coming out from the separator. An Arduino is programmed to calculate the liquid flow rate based on the signal that it receives from the load cell as well as the time interval that the container collects liquid. It also collects analog signals from the existing inlet steam flowmeter. With the two flow rate signals received, the steam quality can be successfully calculated.
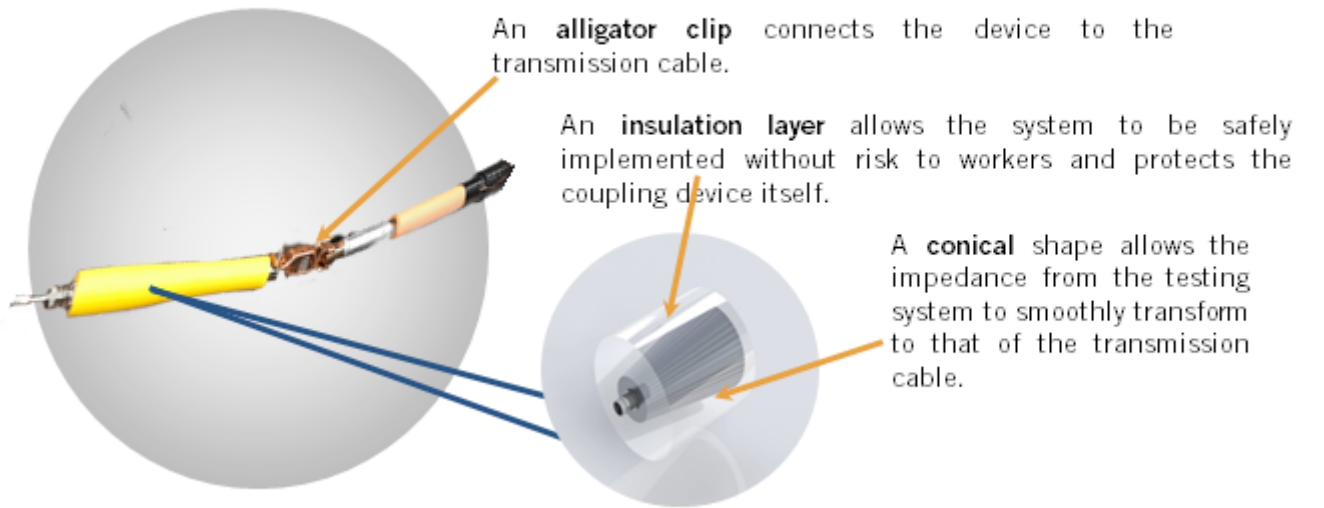
The Fault in Our Cables: An impedance coupling device to improve cable testing for Kinectrics Inc.

Client: Kinectrics Inc.
Team Members: By Nabaa Al Kassab, Stela Emiri & Cissy Yao
Supervisor: Eric Diller

How Can Noise Be Reduced in Transmission Power Cable Testing?

- Kinectrics Inc. provides life cycle management solutions in power generation and electricity transmission/distribution, and requires a method to improve the accuracy of cable tests.
- Keeping transmission cables in proper operating condition is important to continuous services, especially in large facilities like nuclear power plants. This device will provide more accurate test results and an easier testing method for Kinectrics.
- This impedance coupling device could benefit all of Kinectrics' clients, especially those with large power plants. This would help power plants budget better and potentially decrease electricity costs.
- The objective of this project was to create a method to decrease impedance mismatch of the transmission cable and the testing system to reduce noise and accurately detect flaws in cables.

Decreased Noise and Improved Signal Transmission

- The team approached the problem with a mechanical engineering mindset and provided a geometric solution rather than a network (circuit) solution.
- Similarly to how a wide funnel would allow for pouring of liquid without turbulence in comparison to a thin funnel, the impedance matching device decreases signal noise.
- The test results show that the impedance matching device significantly reduces the amount of noise and maintains the energy of the signal as it travels across the cable.

THANK YOU

The Department of Mechanical & Industrial Engineering would like to thank our Capstone clients. Through your support, our MIE students have gained an invaluable experience that will serve as a solid foundation for their future.

Advanced Research Laboratory for Multifunctional Lightweight Structures

Air Canada

Borealis Wind

Canadian Tire

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Dana Incorporated - Shanghai

Dept. of MIE Machine Shop/UG Labs

Dept. of MIE Undergrad Labs

Environment and Climate Change Canada-Meteorological Service of Canada

G. Cinelli-Esperia Corporation

GlobalMedic

Growing North

HiHo Mobile

Intelligent Engineering Solutions

Interface Fluidics Ltd

Kinectrics

LoyaltyOne

MacDonald, Dettwiler and Associates Ltd.

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