

"Not All Those Who Wander are Lost": Route-Finding in First-Year Engineering Design

Prof. Marjan Eggermont, University of Calgary

Marjan Eggermont is the current Associate Dean (Student Affairs) and a Senior Instructor and faculty member at the University of Calgary in the Mechanical and Manufacturing department of the Schulich School of Engineering, University of Calgary. She teaches graphical, written and oral communication in their first Engineering Design and Communication course taught to all incoming engineering students. She co-founded and designs ZQ, an online journal to provide a platform to showcase the nexus of science and design using case studies, news, and articles. As an instructor, she was one of the recipients of The Allan Blizzard Award, a Canadian national teaching award for collaborative projects that improve student learning in 2004. In 2005, she was one of the recipients of the American Society of Mechanical Engineers Curriculum Innovation Award. She is - as PIC II chair - currently a board member of ASEE.

Dr. Denis Onen, Schulich School of Engineering, University of Calgary

Dr. Onen is a registered professional engineer with a broad industrial background in electrical engineering in electronics and embedded systems, integrated circuit design (signal processing and cryptography), biomedical engineering (imaging and instrumentation), and downhole sensing for oil and gas. Dr. Onen is a senior member of the IEEE and is a faculty member in the Schulich School of Engineering, University of Calgary, where he teaches courses in design and professional practice and conducts research in engineering pedagogy.

Dr. Derek D. Lichti, University of Calgary

Derek Lichti is Professor and Head of the Department of Geomatics Engineering at the University of Calgary, Canada. He is also Editor-in-Chief of the ISPRS Journal of Photogrammetry and Remote Sensing. His teaching and research interests are in close-range photogrammetry and active imaging systems (lidar and range cameras) for applications in documenting the built environment, structural monitoring and the measurement of human motion.

Dr. Mark Petovello, Geomatics Engineering, University of Calgary

Dr. Mark Petovello is professor in the department of Geomatics Engineering at the University of Calgary. His research investigates new positioning technologies, including satellite-based navigation, inertial navigation and multi-sensor integration.

WORK IN PROGRESS: Not all those who wander are lost: Route finding in first year engineering design

Abstract

A geomatics-themed project was piloted in a cornerstone engineering design course with a total of 700 students. This paper reports on the structure and delivery of this project, which faced the challenges of limited student knowledge of engineering skills and analysis. However, the Geomatics project used common tools (GPS enabled smartphones and smartphone apps) which were easily understood by students and did not require any particular support from Geomatics faculty. The structure of the project involved student teams developing a set of waypoints and routes between the waypoints, on a university campus. A story or theme was required to be developed by the teams to select the waypoints and routes and which had two benefits; the first was that students explored their campus; and second was the students took ownership of the project and could better rationalize their design decisions. This paper will discuss project outcomes, illustrated by samples of student work and an increased recognition of a non-traditional engineering discipline. This paper will also discuss the lessons learned for future design projects as we discovered many aspects of the engineering design process that are normally not highlighted by standard product design projects.

Introduction

At the University of Calgary, student selection of engineering discipline occurs at the end of the freshman year on a competitive basis for entry in the sophomore year. In order to promote student awareness of Geomatics engineering, a non-traditional and rapidly growing engineering discipline, we collaborated with our Geomatics department to develop a Geomatics-themed project in our cornerstone freshman Design and Communications course. As introductory background for our students, we advised that by possessing skills in the collection, analysis, interpretation and presentation of spatial data, Geomatics engineers develop solutions to location-based problems, and we gave examples of several engaging applications. In terms of organization, students are self-organized in teams of three to four members and they remain with their team for the duration of the course. The teams complete five design projects, ranging from one to four weeks' in duration. We provide four workshops to support student success, delivered by our Psychology department on topics ranging from team dynamics, team effectiveness, and conflict resolution, and include two online assessments with computer generated feedback.

During the development of this project, we realized the pedagogical value of asking our students to take a traditional design process as described by Dominick [1] and apply it to a Geomatics route-finding problem with the following steps:

- Design Problem
 - Problem Statement
 - Functional Requirements
 - \circ Constraints
- Design Options

- Selection
- Prototyping
- Testing and Validation

Normally we ask our students to apply the design process to product design in order to create a mechanical or electro-mechanical design. Product design seems rather straightforward to students and they generally have little difficulty following the design process but are limited by their knowledge of engineering science. This leads to difficulty for design trade-off analysis in terms of quantification and assessment of design alternatives. Our experience in freshman product design echoes the differences in beginning vs informed designers as described by Crismond [2], where premature problem-solving attempts characterize beginning designers.

Students were asked to develop the design parameters for their routes to facilitate the development of evaluation criteria for their routes. This then facilitated the development of their design options and selection process (i.e. their design tradeoff analysis). This project exposed the students to an alternative application of the design process which was to a design project that was outside the traditional product design space and which facilitated the development of sensible and effective design tradeoffs.

Since we had never run a project like this and the literature did not show any similar projects, we were uncertain whether the students would be successful in completing the project and whether the mapping tools would pose too great a challenge for them to research and learn on their own.

Geomatics Route-Finding Project

Resources

The resources available to assist students were: online modules describing the design process (run in a flipped classroom format); suggestions for several GPS and mapping applications (e.g. Runtastic [3] and Google Maps [4]), instructor and teaching assistant support; and an introductory presentation to Geomatics engineering.

Requirements and Constraints of Waypoints and Routes

The Geomatics project required the students to use our university campus as a base to assign four geographically distributed waypoints that their routes must pass through, constrained as follows:

- Must be confined to within campus boundaries
- The total route length must be at least 2500 m;
- At least one waypoint must require a road crossing to access;
- At least one must be located in a parking lot;
- At least one must be located at or near a residence building;
- At least one must be located at or near an academic building;
- The route must end at the starting waypoint: and
- Each route must be subject to at least three optimization criteria (i.e. design factors), and the best must be identified using a force field analysis.

Themes

The selection waypoints and the routes between the waypoints were to be guided according to a theme developed by each student theme. An example theme given to students was that of a "day in the life of a professor," with the following details:

- The professor arrives a little late to the campus parking lot and must quickly get to lecture, but must also pass by a coffee shop to buy coffee
- After lecture, the professor is frazzled and needs a leisurely walk, past a beautiful setting, to go to the gym and exercise
- After exercise, the professor needs to buy and eat a healthy lunch
- After lunch, the professor needs to go back to the parking lot to leave for meetings off campus.

There were a large variety of creative themes developed by student teams, including:

- "Fresh Air," with the goal to get as much fresh air, while recovering between lectures
- "Culture tour", with the goal of seeing the most meaningful art pieces and structures on campus, while passing washrooms and study areas
- "Nature Lover's Tour," to see natural features on campus, including sitting areas and sustainable practices (e.g. electric car charging station, community garden).

Waypoints Selection and Routes Selection and Analysis

Given the requirements and constraints, and the theme developed by the students, various alternative solutions were generated by the students, a sample is shown below in Figure 1. The figure shows two examples of three alternative routes (red, black, and blue lines) between two waypoints (yellow, blue, green, and magenta squares), bounded by the campus border (blue line).



Figure 1 Student Sample - Route Alternatives between Waypoints for "Culture Tour" [4]

Students validated that their waypoints met the requirements and that their total route length was at least 2500 m. In the Figure 1 sample, the team's theme was "Culture Tour" and the students identified note-worthy locations, then developed the alternative routes to encounter them. This team developed sophisticated metrics to score their design criteria:

- **Campus Culture Measurement (of art piece):** aesthetic quality; history of piece on campus; and interactivity of piece. This is a subjective measure that the students could have improved by specifying the quantization methods.
- **Distance Measurement:** route distance determined by walking and using a GPS-enabled device. The students wisely avoided using walking time, as this is a highly variable between people
- **Bathroom Value Measurement:** The first bathroom encountered is scored as a 3 and every subsequent bathroom scored 1 point.
- **Study Area Value Measurements:** The first study area encountered is scored as a 3 and every subsequent study area scored 1 point.

Another team was able to quite successfully specify a sophisticated quantization scheme for their design parameters, as shown in the excerpted sample below for the "Nature Lover's Tour."

Given the four selected waypoints, two routes options were mapped onto Google My Maps to travel between each of the waypoints. This resulted in a total of twelve routes between the four waypoints.

A force field analysis using the theme optimality criteria was used to analyze each one of the twelve routes to determine which route was the most optimal. To score the percentage of the route traveled outside, the route was given a scoring of the following: 1 when the percentage was less than 50%, 2 when the percentage was 50% - 80%, and 3 when the percentage was over 80%. To determine the route scores for the number of sustainability projects passed on campus: 1 was given to the route if it passed by 0 - 1 projects, 2 for 2 - 4 projects, and 3 for greater than 4 projects. The last factor, quality of indoor and outdoor sitting areas, was a subjective evaluation based on group members' opinions of the route and its atmosphere. The first two factors were weighted twice as much as the third as they were more important to the theme. From this scoring system, the optimal route between every two waypoints was determined.

This team labeled their four waypoints as A, B, C, and D, and performed a force field analysis on the routes between each waypoint, according to Table 1, with higher scores being better.

Table 1 Student Sample – Force Field Analysis of Routes Between Waypoints for "Nature Lover's Tour"

	Percentage of Route Traveled Outside (Wt 2)	Number of Campus Sustainability Projects (Wt 2)	Quality of indoor/outdoor sitting/resting areas (Wt1)	Total	Total Distance Traveled (meters)
AC Route 1	3	3	2	14	1352
AC Route 2	2	3	2	12	1352
BD Route 1	3	3	2	14	740
BD Route 2	1	3	-1	7	756
CD Route 1	3	1	1	9	740
CD Route 2	3	3	2	14	1046
AB Route 1	2	1	-1	5	306
AB Route 2	3	2	-1	9	644
BC Route 1	2	3	3	13	1062
BC Route 2	3	3	2	14	1126
DA Route 1	3	2	-1	9	660
DA Route 2	2	3	-1	9	901

Forcefield Analysis of 12 Route Options

From Table 1, the best routes between each waypoint were selected to develop a combination of routes, in which a second force field analysis was developed, as shown in Table 2.

Final Route Selection Forcefield Analysis								
Option 1		Option 2		Option 3				
A-C	14	A-C	14	A-B	9			
C-D	14	C-B	14	B-C	14			
D-B	14	B-D	14	C-D	14			
B-A	9	D-A	9	D-A	9			
Total	51	Total	51	Total	46			
Distance	3781	Distance	3878					

Table 2 Student Sample – Force Field Analysis of Final Routes for "Nature Lover's Tour"

Table 2 shows that the highest scoring options were 1 and 2, tied at 51. The students used distance to break the tie, and Option 1 was selected. This team's final route is shown in .



Figure 2 Student Sample – Final Route Selected for "Nature Lover's Tour" [3]

Geomatics Project Schedule of Student Activities

The project was divided into two main components with the first two weeks as the route finding exercise and the third week as an application of their skills and experience to develop a route that would create graphic when viewed on a map.

Week 1

Lab Period: record design process in logbooks:

- Articulate the design problem
- Define the functional requirements
- Identify the constraints
- Identify initial themes
- Specify initial design factors for use in force field analysis
- Define a schedule for completing the project.

The logbook was graded at the end of the 3-hour lab period to check that each team understood the design problem and had a satisfactory start.

Post-lab:

- Select the final theme and design factors
- Develop the route options between waypoints and gather data by walking the routes
- Analyze the data and use force field analysis to select the best routes between waypoints, according to their theme and design factors
- Prepare a presentation to describe their design process and final results

Week 2

Lab Period: Deliver 10-minute presentation on their design process and final results with all team members participating.

Post-lab: Prepare a 6-page project report describing their design process and final results.

Week 3

Pre-lab: Each student to develop a route that represented a graphic when viewed from the air (e.g. on Google Maps) and to record the route in their logbooks. Guidance for the graphic was that it could represent a word, shape, symbol, etc., and that it would be graded based on quality, complexity, and aesthetic value. This activity utilized the students' newly gained knowledge of the campus and the GPS mapping tools (and their limitations), to develop a creative map graphic.

Lab Period:

- Submit project report, from activity in the first two weeks
- Each team to hold a brainstorming session to discuss and select the route/graphic to be walked and recorded for presentation. Each team to also develop a safety plan, for approval before setting out. Particularly challenging for walking the route, was that the

GPS signal would often be lost whilst indoors so that the mapped route would have jumps, and degrade the graphic quality. Another challenge for students was maintaining the correct path whilst walking. Both of these challenges often resulted in students reinterpreting their graphics as different from their intended graphic.

• Presentation of each team's route, safety plan, and design process, in the third hour of the 3-hour lab period

The graphics were subjectively graded by a teaching assistant and the points awarded were minimal. The students were quite successful in completing this assignment and their graphics included the university mascot, Greek symbols, animals, and the course name, amongst many other graphics.

Lessons Learned

Our initial reservations regarding the complexity of this new project for us and the accessibility of GPS and mapping tools were unfounded. Students were easily able to master the GPS and mapping technology on their own and went well beyond the tools that we had suggested and needed no additional support. We found that students went well beyond our expectations with many teams developing far more route options and design factors for evaluation than our minimum criteria. At least one team tested several GPS apps against the campus running track to determine which was the most accurate distance measuring app!

In student evaluations, we found that students considered this Geomatics project as a lighter load compared to our other projects, so we will broaden the scope of this project in future years. We also observed a side-benefit of this project, it gave our freshman students a good excuse to explore the campus, which was a new environment for most of them.

We also found that many students struggled with developing clear quantization methods to specify how they assigned numerical values to their design factors. It looked like they made up some numbers, rather than developing an explicit scale, as shown in the excerpt sample above. The root cause of this problem can be traced to an incomplete example we gave the students to illustrate the force field analysis. In a future iteration of the course we will provide more guidance and examples to show how to quantify values for their design factors.

We observed that students were able to develop multiple design factors to produce multiple objective optimization for their decision process in order to select their best route. This models the practice of informed designers as described by Crismond [2], where design decisions are made after the problem is explored and framed. This is in contrast with freshman product design projects where we have found that students have significant difficulty in developing satisfactory design factors to guide their design selection process due to their limited engineering knowledge. Our experience with freshman product design shows that students often develop multiple, alternative prototypes, to explore the design space in a haphazard manner [2]. This is certainly a valid design approach, but which does not scale well to professional practice where engineering analysis would largely guide the informed design selection process.

References

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