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Further Development of Capstone Design Project Courses based on a Case Study

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ABSTRACT

Capstone design project courses for Engineering Technology (ET) programs are designed to develop students' skills to help apply technical knowledge to solve complex engineering and technological problems with practical applications. In many cases, these courses focus on the technical aspects involving engineering design and analysis, prototyping, testing, and improvement. Although this emphasis addresses the requirement for development of technical skills, it usually overlooks potential effects of non-technical factors on a project in practical applications. This paper investigates the potentials and reports initial experience and findings to further develop these courses so that non-technical topics such as developing a business plan and conducting a market study can be incorporated. As a first approach, course materials introducing students to the fundamentals of running a business has been developed and incorporated into the instruction of these courses. Initial results observed shows that the ET students are greatly interested in non-technical side of developing a product. The ultimate goal is to have students from other disciplines such as business, finance, and marketing to work with ET students so that they can experience the complete product development process.

As a case study, this paper discuss a senior design project carried out by a mechanical engineering technology student. The project focuses on design and fabrication of a utility trailer with a height adjustable main deck targeting the market of towing needs for riding utilities such as motorcycles and utility vehicles. Using a fully self-contained pneumatic system which powers two air bags functioning as both dampeners and springs in a set of custom designed trailing arms, the trailer allows the main deck to be lowered to ground level which makes loading/unloading more convenient and eliminates the need for loading ramp. This paper presents the technical skill sets the student demonstrated in the process of designing the trailer as well as challenges that are non-technical to further develop and commercialize it.

INTRODUCTION

Capstone design project courses have been widely adopted in ET curricula spanning various disciplines by many institutes.[1,2,3] Prolific literatures discussing numerous projects successfully carried out by students with various engineering and technological backgrounds have been published with technical details.[4,5] Since ET programs focus more on the application of technologies, emphasis on developing projects with industrial partners is becoming a trend and studies have shown great success in many cases.[6,7] Teaching methods and assessing mechanisms emphasizing different aspects that modern engineers and engineering technologists are facing such as time management, team work, communications, and ethics have also been developed and incorporated in these courses to resemble experiences in practical projects.[8,9] There is no doubt that capstone design courses have been very successful at developing students' problem solving skill by allowing them to apply knowledge learned from courses to synthesize solutions to practical problems.[10,11]

When the ET program was first established at the Southeastern Louisiana University in 2009, capstone design courses spanning two semesters were implemented. The first semester focused primarily on the design and analysis aspect, and the second semester on the prototyping, testing, and finalizing the projects. The two-semester capstone design project is required core component for all the four concentrations in the ET program: Computer, Construction, Mechanical, and Energy. Upon successful completion, students should fulfill the following course educational objectives.

- Understand the objectives of engineering design projects
- Have a better understanding and hands-on experience in various stages of engineering design
- Develop experience in teamwork, project planning, execution, and monitoring of engineering projects
- Develop experience in technical communication in both written and oral formats
- Understanding how to design by objectives
- Understanding ethical issues associated with engineering design process
- Conduct hands-on design, analysis, and fabrication associated with projects

As an example, this paper presents the procedure followed initially for instruction of the capstone design project courses. Since the procedure focuses only on the technical aspect of product development, it limits the practical application of the project. Potentials and possibilities as well as challenges to further develop these courses to include non-technical components such as market study etc. that are essential parts of a complete product development cycle are discussed. The first attempt to develop and incorporate course material introducing fundamentals of starting a small business and preliminary results observed are also presented.

PROCEDURE OF CAPTONE DESIGN PROJECT COURSES

As an example, this paper presents the requirements for students with Mechanical Engineering Technology concentration, which consists of more than 50% of the total enrolled students in the ET program at the Southeastern Louisiana University. When students start the first semester, their immediate task is to identify projects that are appropriate for their areas of study. There are typically three sources for projects: 1) projects proposed and sponsored by industrial partners; 2) projects proposed by faculty that are typically related to their research topics; 3) projects proposed by students with their personal interests or goals. In all cases, a qualified project must consist of engineering design and analysis contents that are sufficient for a student working alone or a group of students working as a team. During the first three weeks, it is required that all students need to discuss with faculty in the department to propose and identify their projects. At the end of the third week, students are required to submit a project proposal to include the following essential components for approval:

- A brief background introduction of the proposed project including current development, challenges and problems it is facing and proposed improvements
- A list of objectives to be achieve when the proposed project is accomplished at the end of the second semester
- A description with schematics and diagrams demonstrating the main engineering design and analysis components as well as the associated tools and programs to be used
- A list of deliverables and results that will be presented at the end of the project
- An outline of a project timeline that identifies milestones indicating progression towards the deliverables

When the proposed projects are approved, students are required to discuss with faculty and select a faculty member, or a group of faculty members, with expertise that are closely related to the proposed project to serve as their faculty advisor(s). Students are also required to arrange a weekly meeting with their faculty advisor(s) to report their project progress and discuss their plans throughout the semester. As the semester progress, students will submit a mid-term report and present orally their advancement towards the goals outlined. At the end of the first semester, students will give an oral presentation and submit a report to include the following details of the project.

- Complete design that is ready for fabrication and construction
- Calculations and analysis conducted with details such as design and analysis tools used, assumptions made, detailed steps showing calculations and analysis conducted, and results obtained
- Compliance to the proposed deliverables and timeline
- A bill of materials to list both purchased and custom fabricated components required for construction of a prototype
- Outlook and plans for the second semester

When students enter the second capstone design project course, an updated proposal is required to be presented and finalized before starting the prototyping and fabrication processes. The main purpose of this step is to recap the design and analysis completed in the first semester and to include any minor modifications or improvements. As the project advances to the fabrication and construction stage, students are still required to meet with their faculty advisor(s) weekly to report their progress and plans until completion of the project. Typically, issues such as design defects, manufacturability, and material selection arise during this stage requiring further modification to the original design. At the end of the second semester, students will submit a final report to include the finalized technical details similar to those required in the first semester and a physical prototype demonstrating planned functions based on the design and analysis conducted. An oral presentation is required and all faculty members and a group of industrial partners including engineers, project managers, HR experts, and executives will evaluate it.

A CASE STUDY

Since the introduction of the two semesters capstone project design courses in the Fall 2009 semester, many projects have been proposed with a few failed ones and many more successful ones. As a case study, this paper discusses a capstone design project carried out by a mechanical engineering technology student in the Fall 2014 and Spring 2015 two-semester sequence.

Background:

The project focuses on the design and fabrication of a utility trailer equipped with a height adjustable main deck targeting at the market of towing needs for riding utilities such as motorcycle. Using a fully self-contained pneumatic system which powers two air bags functioning as both dampeners and springs in a set of custom designed trailing arms functioning as swing arms, the trailer allows the main deck to be lowered to ground level which makes loading/unloading more convenient and eliminates the need for loading ramps for the end users. When preparing the trailer for travel, the main deck is adjusted to a ride height matching that of the hitch on the towing vehicle. As a result, possible hazardous conditions associated with an uneven main deck such as sway and loss of traction due to hard braking, strong wind, and fast turning can be avoided,[12,13] which in turn reduces injuries or even fatalities due to accidents caused by these conditions in towing scenarios.

Objectives:

To achieve the goal of allowing the trailer bed to be lowered to the ground level, the trailer frame needs to be lightweight with a slim profile, yet still have a designed 2,000 lbs load capacity. To ensure that the trailer is still operational when towed by any vehicle, a self-contained design to include a 12V DC powered air compressor, properly rated air bags, pneumatic control and monitoring system, and safety equipment is integrated into the trailer. A real-time monitoring system that can be mounted inside the towing vehicle, which displays the system status such as air pressure in the air bags, main tank pressure, and compressor status, is also developed.

Proposed design and analysis:

Since the trailer deck requires height adjustment from ground level, a traditional fixed axel design is no longer suitable. Instead, a trailing arm similar to the swing arm suspension design used in all-terrain vehicles (ATV) is developed. This trailing arm functions as a lever that lifts and lowers the trailer deck. The trailing arms is designed to link together the airbags, shocks, and hubs of the trailer. Since there is no trailer utilizing trailing arm design in this manner exists, strength of all components under various loading conditions is analyzed. The designed load capacity and sideway forces due to turning at travel speed are the two main load conditions that are studied. Figure 1 shows a schematic of the trailer in lowered and raised positions.

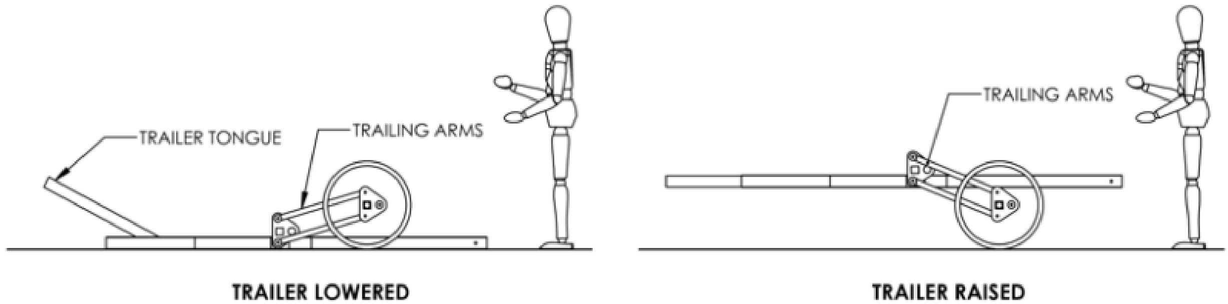

Figure 1 Schematic of the trailing arms and trailer in lowered and raised positions

COMSOL finite element analysis (FEA) software is used to conduct stress analysis in this project.[14] The journal stress exerted on the hub is analyzed so that a proper hub diameter can be determined. For maintenance consideration, a standard off the shelf hub is purchased and used as the hub. Stresses and deflections due to bending as well as other loading conditions on all custom made components and the trailing arms are all evaluated. The lifting force of the air bags required is calculated in order to select properly rated air bags and their optimal running pressure. Shearing stress on all main bolts is also analyzed. The proper shock ratings that complement the air bags while maximize the trailer capacity is also calculated.

All components including the ones bought off the shelf and those custom designed are all modeled in SolidWorks for development of a final trailer assembly. This includes the complete trailer frame, trailing arms, wheel assembly, hardware, air management components, shocks, lights, electrical wiring, and any other accessories. This assembly is also used to check for possible interferences amongst moving components, to calculate trailer gross weight, ground clearance at different deck heights, and the overall center of gravity (COG). Models of the custom designed components are also used to develop technical drawings for fabrication. Combining with specifications provided by suppliers of the bought off the shelf components, a detail bill of materials including all parts used in the final assembly is developed.

Deliverables:

At the end of the first semester, the design of the trailer including all components and an assembly is developed using SolidWorks. Along with the technical drawings for all custom fabricated parts, a detail bill of materials is developed. The following list outline the tasks associated with the planned deliverables.

- COMSOL stress analysis
    - Trailing arm: mounts, hub, & bolted joints
    - Hub
    - Tongue pivot joint
    - All tie down location
- SolidWorks modeling
    - All trailer components and final assembly
    - All compressed air system components
    - Airline and electrical wiring
    - Total trailer weight and COG
    - Motion study
    - automatic bill of materials
- Calculations
    - Bending stress and deflection in all load bearing components
    - Hub journal stress
    - Shearing stress in all critical bolts
    - Maximum trailer weight rating

Timeline

The following list is the timeline and associated goals for the first semester.

- Submit project proposal and then present and gain approval — Oct. 08, 2014
- Complete initial design using SolidWorks — Oct. 31, 2014
- Finalize initial design after motion study — Nov. 17, 2014
- Conduct and complete related calculations — Nov. 26, 2014
- Develop all technical drawings for custom designed parts — Dec. 01, 2014
- Submit final report and presentation — Dec. 01, 2014

In the second semester, the project focuses primarily on the fabrication, testing, and final adjustment of the designed trailer with the updated timeline shown below.

- Complete fabrication of trailer frame — Feb. 28, 2015
- Complete fabrication weldments — Mar. 07, 2015
- Initial trailer assembly — Mar. 28, 2015
- Testing/Registration with state — Apr. 18, 2015
- Implement any design alterations — Apr. 25, 2015
- Final trailer assembly — May 02, 2015

Results

Following the proposal, the project is carried out and all tasks are accomplished according to the planned timeline. Figure 2 shows the final assembled trailer, and Figure 4 to Figure 7 show the associated designs, analyses, and fabrications carried out throughout the two semesters. Table 1 and Table 2 show the parts that were purchased and were custom fabricated correspondingly.

Figure 2 Final assembled trailer

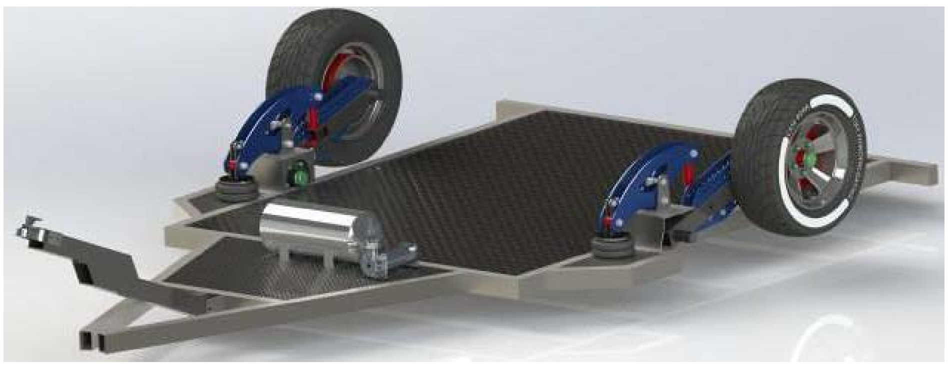

Figure 3 SolidWorks full assembly model

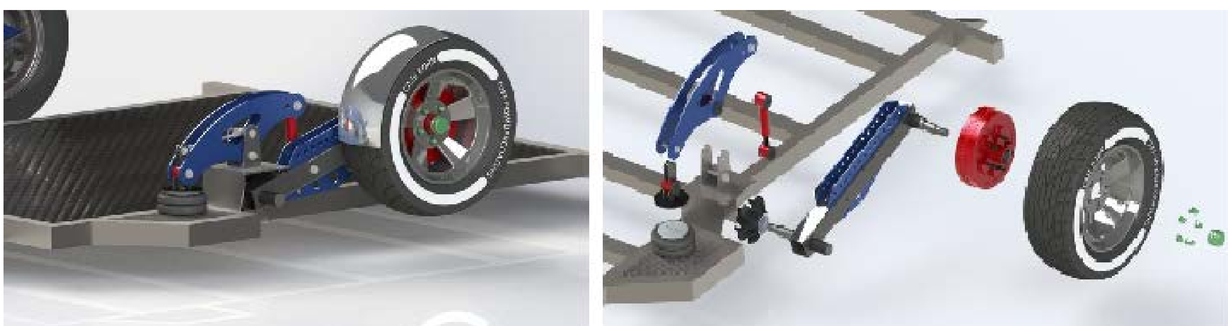

Figure 4 Trailing arm design

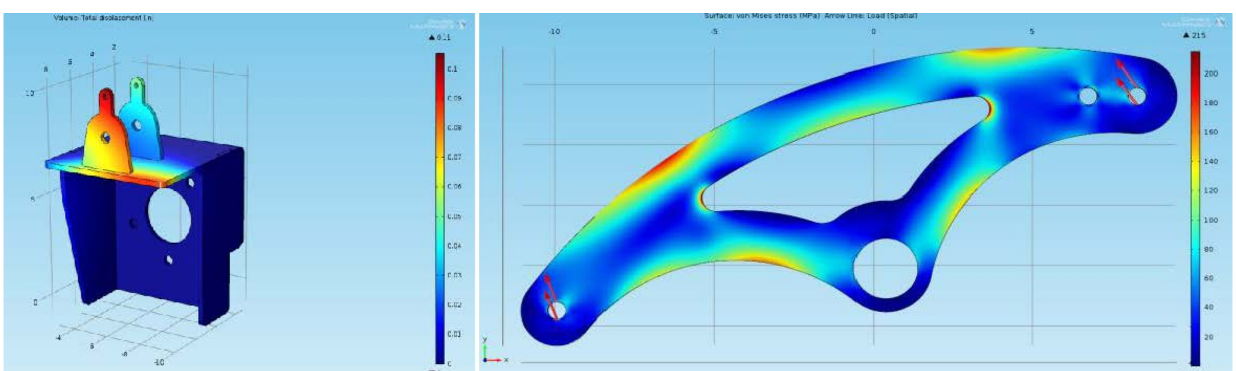

Figure 5 Example of stress analysis for load bearing components

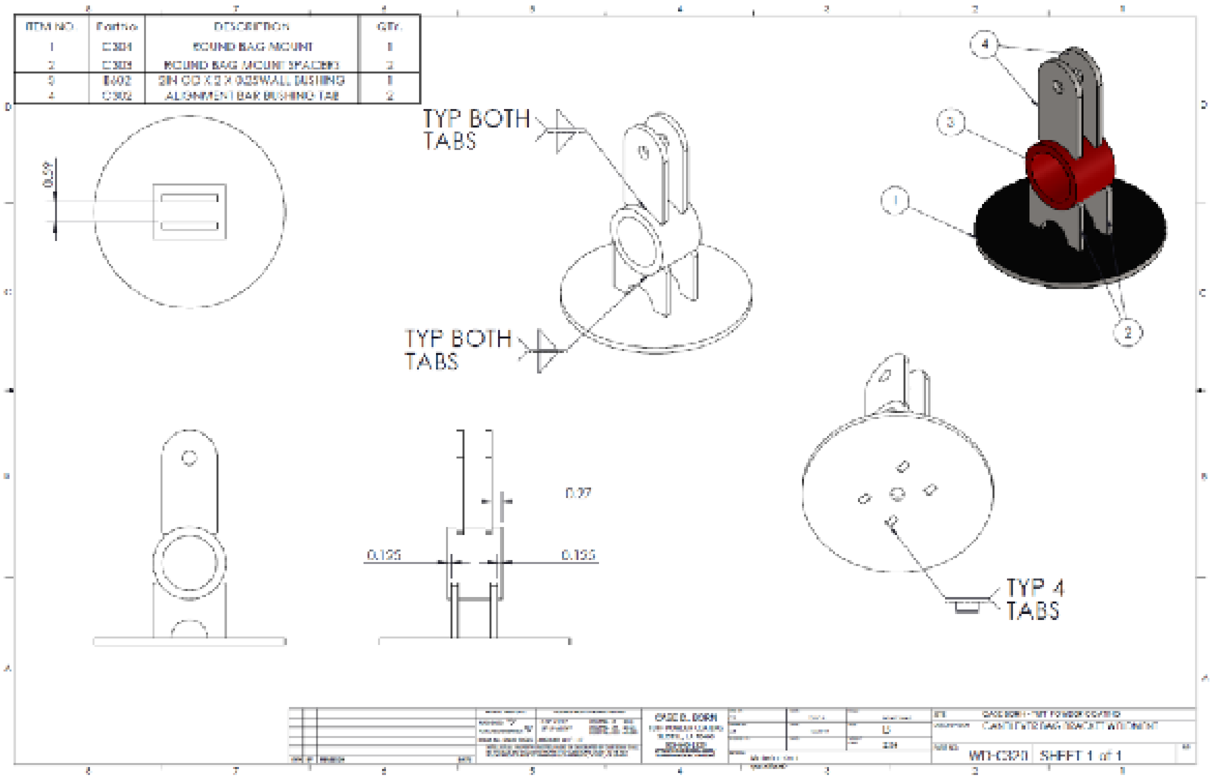

Figure 6 Example of technical drawing of custom fabricated component

Figure 7 Example of custom fabricated components

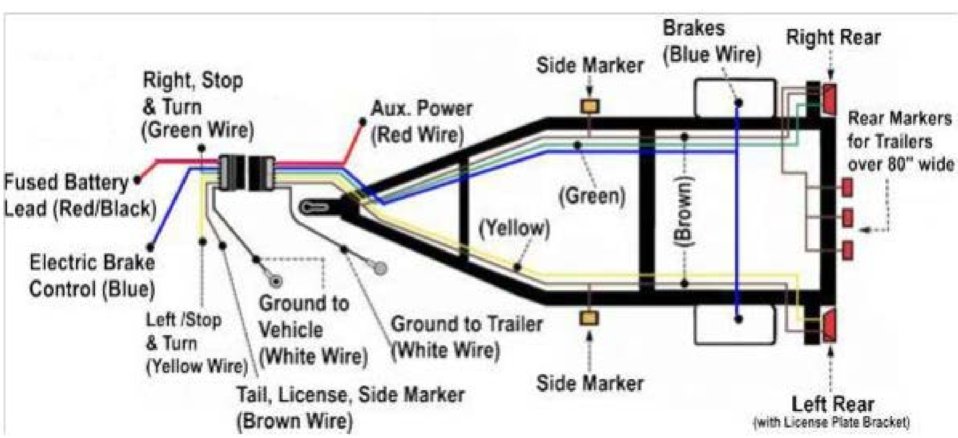

Figure 8 Wiring diagram of the pneumatic system

PARTS ORDERED			
Part Number	Description	On Hand	Need
84546UC3	Trailer Hub And Drum Assembly - 3,500-lb Axles - 5 on 4-1/2	2	2
TRBK10E01	TruRyde Electric Brake Assembly - 10" - Left Hand	2	2
84545BX	Dexter Trailer Hub Assembly - 3,500-lb Axles - 5 on 4-1/2	2	2
T0872400	Titan Brake Flange for 1-3/4" Round Axles	2	2
R2061-284	Spindle 1.75" RDx 6.5" STUB	2	2
20099	Engager Trailer BreakAway Kit with Charger and Tester	1	1
H20043	7-Way Molded Trailer Wire Connector, 4' Long	1	1
-	LED Light Kit	1	1
RR01-C	Brophy D-Ring Anchor - Zinc Plated Steel - Recessed Mount - 1,200 lbs	9	9
HT87073	Husky Channel Tongue Trailer Coupler - Zinc Plated - 2" Ball - 2" Channel - 3,500 lbs	1	1
2118-348-04	48" Long Safety Chain with 7/16" Hooks, 5,000 lbs.	1	1

Table 1 Parts bought off the shelf

FABRICATED PARTS			
Part Number	Description	On Hand	Need
WD-F100	Trailer Hub And Drum Assembly - 3,500-lb Axles - 5 on 4-1/2	1	1
WD-H200	Hub Housing Weldment	2	2
WD-C300	Cantilever Body Weldment	2	2
WD-C320	Cantilever Bag Bracket Weldment	2	2
WD-T400	Trailing Arm Weldment	2	2
WD-D500	Adjustable Dog Bone Weldment	0	2

Table 2 Parts custom fabricated

DISCUSSION

Both the faculty and the industrial partners unanimously voted this project as the first place amongst all the capstone design projects presented in the Spring 2015 semester. It is obvious that the student demonstrated the skill sets required to apply design and analysis methodologies as well as to use appropriate tools to solve practical problems associated with development of a new product. To some extents, the student showed knowledge and skills beyond requirements for an ET program.

As outlined in the timeline, the student applied and received certification from the state trooper so that a title and a license could be issued to the trailer. Since the student paid for the components and had all the fabrication done at his private facility, he kept the trailer for his hobby needs. The benefits of the trailer is apparent when compared to traditional ones, and there is a potential market for it. Conversations discussing the possibility to manufacture and market this trailer were exchanged. However, upon revisiting the whole process of the project starting from proposal to fabrication and finalization, more questions other than answers were raised from the perspective of business.

The first and most likely the most important question is how much does it cost to make the trailer? Even if the costs associated with the initial stages such as time, effort, and other investment in the design and analysis stage as well as cost of tools including the SolidWorks and COMSOL software are excluded, the direct costs to fabricate all the custom designed components are still hard to calculate. For example, the key component for the trailing arm mechanism is the cantilever body weldment, which was fabricated by welding four stainless steel plates cut to the designed shape and dimension by a laser cutter as shown in Figure 7. Since the laser cutting manufacturing process was performed at the facilities of an industrial partner, and the parts were donated to the project, the costs of the materials, manufacturing and labor associated are hard to calculate. In addition, all the welding related work throughout the whole project was completed by the student using his own welding machine and supplies.

The second question is that although there is definitely a market for the trailer, what is exactly the current status of the market, and how big is the market? Initial research shows that there is no similar products available, and fixed height trailers combined with loading ramp are used for similar intended purpose. The question is then what are the currently available products in the market? What is the typical cost of these competitive systems? With the additions of the custom made trailing arm, air bags, compressed air system, monitoring system etc., the cost of the trailer developed in this project is certainly higher than the traditional ones. At what retail price, will the trailer be competitive, and ensure profitability at the same time?
The third question is how to finance the startup? Although there are many funding sources such as government grants, venture capitals, bank loans, and online lending portals etc., what are the procedures and necessary documents to apply for these funds? In addition, how to estimate the amount of initial investment based on restrictions is also a big question.

The fourth question is what are the strategies and channels to promote the sales of the trailer as well as how much do they cost? One of the key factors affecting sales of any products is the price. Whether the price is affordable and competitive to similar products from competitors greatly affect product sales. On the other hand, a reasonable price determined by market research could also affect design and manufacturing to ensure profitability. If market study shows that the competitive retail price is lower than the cost to fabricate the trailer, which means financial loss, alterations to the design, manufacturing processes, or material selections would be necessary to lower the cost so that the project become profitable.

The last but not the least is the supply chain involving acquisitions of supplies and equipment for production, suppliers for purchased components, transportation and distribution, warehouse operation, and design of services. In addition, other aspects of a typical business such as legal issues, bookkeeping, taxes, and facility are all need to be addressed.

FURTHER DEVELOPEMENT

After revisiting the ET curricula at the Southeastern Louisiana University and curricula of similar programs at other institutes, it is evident that there is a lack, or even absent, of course materials introducing ET students to the business side of an engineering or technological problem. The fact that the current capstone design project courses at the Southeastern Louisiana University focus mainly on the design and manufacturing aspects of product development process provides an ideal platform to incorporate the business aspects into them.

First attempt

As a first attempt, the capstone design project courses started to incorporate course materials offered by the Small Business Development Center (SBDC) running by the Business School at the Southeastern Louisiana University. With the assistance of faculty from the SBDC, the following topics regarding establishing a startup were introduced to students enrolled in the capstone design project courses since Fall 2015 semester.

- Feasibility
    - Why going into business
    - What business is right for you
- Business Plan
    - What is a business plan
    - Purposes of business plan
    - Proposed product
        - Detail description of products
        - Advantages when compared to competitors
        - Projected market share
        - Further development capability
        - Estimated profit margins
        - Supply chain
    - Market study
        - Customer needs
        - Status of current and potential markets
        - Competitions
        - Promotional strategies and plans
        - Industry characteristics
    - Facilities
        - Location
        - Utilities
        - Facilities planning and material handling
        - Fix costs and overhead
        - Compliance to federal, state, local regulations
    - Others
        - Patents and copyrights legal issues
        - Book keeping and taxes
        - Cash reserve for operation

    - Costs associated with building or remodeling facilities
- Funds
    - Sources of funds
    - Qualifying for a loan
    - Collaterals

The introduction of these topics received very positive feedback from students despite the fact that these topics are additional curriculum items. A team of four students was inspired by all these new perspectives of engineering design and manufacturing, and they participated in the international "Startup Weekend" event[15] hosted in New Orleans, LA during October 15-17, 2015. Within a period of 54 hours, 15 teams initially presented their startup ideas to a panel of judges including business school faculty, local entrepreneurs, investors, and business executives. The judges voted down to seven teams to move forward for further development for strategies to launch these promising ideas. During this process, teams are required to go through the complete cycle of product development to include items such as market study, which the team conducted a survey to the targeted buyers of their product, prototyping, financial analysis, and composition of a business plan. The team was selected as finalist and presented the business proposal, which includes details such as the logo of the product, and won 2nd place.[16]

Observations

As the first added requirement, students are required to conduct a comprehensive study of currently available solutions to their proposed projects. The students need to justify the proposed projects not only from the technical aspect to satisfy the educational requirements, but also from the business aspect to make the final products of their proposed projects financially competitive. By conducting such a study, students not only gain a better understanding of the problems associated with their proposed projects, it also help them to develop approaches and solutions that are more viable to the problems. For example, while designing an automatic demolding apparatus for a plastic injection-molding machine, the initial proposed solution is to utilize an array of suction cups operated by a vacuum pump to remove parts from the mold. However, the costs of the vacuum pump and the control system associated with it are high. After studying products available for generating negative pressure, students adopt the venturi solution that is much cheaper, more reliable, and requiring virtually no maintenance.

Challenges

Despite the immediate positive impact upon introduction of these topics related to the business side of product development, incorporating them into the capstone design project courses also faces many challenges. Among all the others, identifying and defining the projects that not only provide sufficient engineering design and analysis contents, but also possess intrinsic value for potential commercialization has proved to be the most difficult. In addition, communication between the engineering side and the business side during the product development process requires better understanding of the engineering language for the business students or vice versa. Only if this communication channel is effective, the best strategies for both design and manufacturing, as well as marketing, can be achieved. Finally, pairing ET students with business students on a two semesters basis as the capstone design project courses were initially designed creates logistic issues since many related business courses are single semester based. Current practice is to involve primarily ET students and business students on a case-by-case scenario. Further discussion, experiments, or even curriculum development from both sides may be necessary in order to achieve the ultimate goal of systematically incorporating students from multi-disciplines into one team for product development representing real-world practice.

Next step

A great product from the technical point view is the one with superior quality such as its functionality and reliability that are typically determined by engineering design. However, whether such a product is successful or not are also determined by factors that are non-technical such as product cost, development time, development cost, and potential for future further development. A practical product development team typically include engineers from different disciplines, manufacturing experts, industrial designers, marketing professionals, specialist in supply chains, finance, sales, service, and legal experts.

The immediate next step to further develop the capstone design project courses is to involve students from other disciplines particularly marketing and finance. In addition to presenting engineering design, analysis, and prototype of a product, students working as a team will conduct market analysis and develop finance plan for the product. To achieve this goal, course content and curricula need to be further developed to address the following additional portions of product development process.

- Market analysis
    - Current market status -- Is there a market? How big is it?
    - Similar products from competitors -- functions; cost; features etc.
    - Identify essential and optional needs of current and potential customers
- Finance plan
    - Costs associated with product development -- development; manufacturing; promotion and marketing; supply chain; service etc.
    - Finance analysis -- both qualitative and quantitative models to analyze costs associated with different features and price
    - Finance plan -- how to finance the project

SUMMARY

The interdisciplinary nature of a product development cycle involves many, if not all, departments in a corporation. Among all the functions, the marketing, the design, and the manufacturing are usually essential to a product development project. Currently, most ET curricula emphasize the design and manufacturing functions, while business programs focus primarily on the marketing and business sides of product development. This paper presents an effort to try to narrow the gap between the two sides with some success and more obstacles to conquer. Future work will be focusing on curriculum and course content developments from both sides.

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