

Senior Design Capstone – A Winning Model

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ABSTRACT

The Senior Design Capstone model at Miami University includes a Project Management Course (ENT 316) and two Senior Design courses (ENT 497 and ENT 498). Following this model, three Mechanical Engineering Technology students planned, designed, built, tested and ultimately won a national design competition for a Basic Utility Vehicle (BUV). This paper describes the courses, skills, planning and analysis.

INTRODUCTION

In 2002 Miami University (Ohio) began offering a new BS Degree in Applied Science with a concentration in Mechanical Engineering Technology. This program contains new courses including: Project Management, Mechanical Vibration and Finite Element Analysis along with other traditional Mechanical Engineering courses. Miami University also requires a group of courses designed to produce a well rounded graduate (called the Miami Plan). The Miami Plan includes courses in English composition, fine arts, humanities, social science, cultures, natural science, and mathematics. Students who accomplished this feat were from the second graduating class from the new BS Mechanical program.

The model followed by this team of three Mechanical Engineering Technology students is the integration of their Engineering Technology and Miami Plan education into a project management and a senior capstone design sequence which ultimately resulted in the design and construction of a transportation vehicle. This vehicle, called a Basic Utility Vehicle (BUV), was designed and constructed to meet the performance specifications of the Institute of Affordable Transportation (IAT), www.drivebuvo.org, a nonprofit organization based in Indianapolis, IN. The BUV is a safe, simple, low cost, low maintenance, easy to manufacture form of transportation for peoples of third world countries [1]. In order to design a vehicle of this complexity the students must research, design, build and test numerous components and sub-assemblies based on their designs. A wide variety of engineering disciplines are employed in this process including conceptualization, research, design, detailing, parts procurement, manufacturing, machining, assembly, troubleshooting, mechanical controls, electrical controls validation, and documentation.

The IAT mission statement is “*To improve lives in developing countries by facilitating the spread of simple vehicles that can be assembled almost anywhere, by almost anyone*”. The IAT organizes a yearly competition for teams from colleges and universities throughout the United States and Canada to evaluate their designs using a

number of performance challenges. The organization also requires that vehicle speed be kept to a minimum and that the design be oriented toward women of developing countries. The premise is that if the maximum speed is low, men will not have interest in the vehicle. Cost is another criterion; if the vehicle is too expensive people in developing countries will not be able to purchase or build the vehicle. The design and performance specifications are broad enough to give students significant freedom and creativity.

On April 30, 2005, the competition was held in Indianapolis in which all engineering universities were invited to participate. Participants in the 2005 competition included: Purdue University – Indianapolis (IUPUI), University of Dayton, University of Cincinnati, Tri-State University, Sinclair Community College, Marquette University, Northern Illinois University, Milwaukee School of Engineering, University of Missouri, John Brown University, and Alfred State (SUNY). The Miami team finished first overall in this competition as well as first in several events.

The following sections include detailed descriptions and synergies of the three Engineering Technology courses involved in this process and their influence in the planning, design and construction process. Examples of the design, analysis, testing and validation are included.

PROJECT MANAGEMENT (ENT 316)

This course covers background, techniques and case studies in project management. The students develop a fundamental understanding of the concepts for defining, organizing and managing both small and large projects. This course is somewhat unique since in Engineering Technology, project managers are managers as well as extremely active members of the team. The development and nurturing of discussion and organizational skills, cause and effect evaluation techniques, conflict resolution processes, cost analysis models and presentation skills are learned skills. The students, upon completion of this course, are able to (1) define what projects are and how they are used in the industrial and manufacturing world, (2) demonstrate the tools and technology requirements for project management, (3) demonstrate the team concept for project operation and management, and (4) demonstrate the process of finding and critically evaluating information in project management. The textbook used for this course is Project Management: A Managerial Approach 5th Edition by Jack R. Meredith and Samuel J. Mantel Jr. John Wiley & Sons Inc. ISBN 0-471-07323-7. A significant number of supplemental readings and Harvard Business Case (HBS) [2] studies are also used. These cases allow students to evaluate, analyze and role play in order to develop skills as a project manager and team member. A number of suggested cases are listed in Appendix I.

The BUV project began with a detailed discussion among three students, Jim Bachmann, Vince Breidenbach, Sean Reed and the author. The initial exercise was to define the project and its requirements using processes developed in the ENT 316. This involved two primary steps. First they attended the BUV competition in April of 2004 to determine the basic requirements for the design and the nature of the competition. Written and photographic notes were made concerning the itinerary of the competition events. Competition vehicles were also studied and evaluated based on design and

performance. The specifications for the 2005 competition were obtained from the Institute of Affordable Transportation.

Second, a project plan was established. This involved the development of a work breakdown schedule, a task list of the necessary steps required for the project and the use of a Gantt chart generated by using Microsoft Project®, which is shown in Appendix II. At this point it became clear that the time and funding necessary were both significant. Once organized and milestones established the process began. A parts list was developed, a preliminary budget was organized and the processes of acquiring the funds and parts were underway. As with any project, the plan is one of the most important aspects. In some cases, planning can take up to 20% of the total time. With this project planning was only about 5%. This is because there were a number of fixed specifications for the project which eliminated several planning steps. For example, the vehicle was required to use a 12' length x 5.5' width 2-wheel drive SUV or truck chassis with differential, a 8.5 to 12 hp internal combustion engine, a 900 lb maximum front end weight, tractor braking and a three wheeled vehicle with front steering.

The students organized a five minute presentation about their project and presented it at a semi-annual Miami University School of Engineering and Applied Science Industrial Advisory Council meeting. The purpose of this presentation was two fold. First it provided an opportunity for the students to organize a proposal for a project. This process involved a guided program of establishing objectives, goals, a project plan, a preliminary budget and a Gantt chart.

Secondly, it provided the students a venue to sell their project to a seasoned group of industrial advisors. It also provided a path to request financial support for their project. The presentation was well received and was rewarded with a grant from CH2M Hill Miamisburg, OH, to fund a large portion of the project. This process is very similar to that which occurs every day in the industrial world.

Thus, project management was the initial step in the process. It focused the students on planning, organizing, budgeting, milestone establishment and team work. These skills and techniques were essential and continued throughout the project. The performance against the time and budget were found to be acceptable. The early planning process allowed the project to begin one semester earlier than normal for Miami's capstone design projects. This process is highly recommended for future planning of curriculum and for others interested in such a project. It provides additional synergies and additional time for design, construction and testing of projects. It also allows for additional interaction among students, faculty and mentors.

SENIOR DESIGN PROJECT (ENT 497)

ENT 497 is normally the planning stage for the Senior Design process. Students are expected to visualize, discuss and look for potential projects. This involves discussion with faculty and industrial mentors and outside companies. Students are also encouraged to organize into teams of no more than three members. The semester involves a series of guest lecturers and special presentations on research, design, cost analysis, ethics, patents

and several others. By the end of the semester the students are expected to have a completely developed and organized project with a budget, time line and funding. Each project team has a faculty and /or industrial mentor. At the end of the semester each team presents their entire proposal in both Microsoft PowerPoint® and written formats to the Engineering Technology faculty. Their grade for the course is based on their oral and written presentations. This part of the process requires the students to include skills learned in the Miami Plan courses. The inclusion of cultural perspective, writing skills, mathematics skills and many others are what separate Miami graduates from other Engineering Technology graduates.

For the BUV project, the process for ENT 497 was completed very early in the semester. In fact, it was nearly completed by the beginning of the semester. This occurred because of the time constraint discovered during planning discussions in the Project Management course. It was clear that if work did not begin early on this project there would be insufficient time to complete it. So for much of the time during the ENT497 semester, students on the BUV project were in the design and constructions stages of the process. This was only possible because they began the process early, organized their thoughts and planned their project well in advance. They were, however, able to make use of the guest lecturers and presentations in order to further refine their design and planning processes. It created a framework for organizing the project and preparing for their final presentation and write-up for the ENT 498 course.

The design of the vehicle was kept simple and included the following sub assemblies: a front end steering assembly, an engine and power train, a driver's compartment, and the cargo bed/ passenger area. Designing various components in a gasoline powered vehicle required knowledge not in the students' portfolio of design knowledge. Thus, to design all of the components required a significant amount of research. This research ranged from major components and assemblies down to research for individual nuts and bolts needed for the assembled BUV. This research included internet searches, catalog and product brochures located at local companies, and hands on visual identification of parts in local stores. Internet searches were used to locate tires, transmissions, torque converters, and chassis bushing. Catalog searches were used for bearings, locknuts, lock washers, and material selection. Visual part identification included coil over shocks, hitch pins, and electrical components.

The conceptualization started with a rolling chassis from 1995 Chevrolet Tracker 4X4, and a myriad of sketches and drawings. The students began with the cargo bed / passenger area, followed by the engine, torque converter, transmission, drive shaft, and roll cage. Design, research, and calculations were performed to determine the torque speed and loads based on a 10 hp Kohler Engine, the rear end gear ratio and tire size.

The front end and steering assembly was based on discovered research from a vehicle designed in the 1970's know as the "Trimuter" [3] [4] [5]. Figure 1 is a solid model on the student's BUV design created using Mechanical Desktop® and Solid Works®. Figure 2 is a digital photograph of the actual constructed assembly. The IAT required that the total cost of front end assembly be under \$1000. The students' design total was \$831.24.

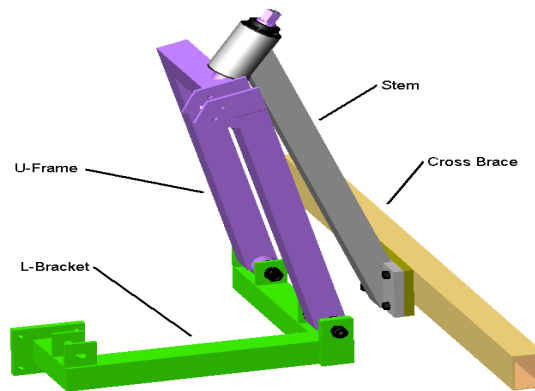


Figure 1 3-D Mechanical Desktop® and Solid Works® model of the BUV front end assembly design.



Figure 2 Photo of the constructed front end assembly of the BUV shown during assembly and testing.

SENIOR DESIGN PROJECT (ENT 498)

ENT 498 is the second semester course for Miami's capstone design course series. Students must complete the design, build and test stages of their projects. They are required to write an extensive report about all aspects of their project, including a reflective essay about their experience. They are also required to present their design and findings to the faculty, industrial partners and academic community at an annual Senior Design forum. This forum includes a table top display and/or model of the project. Their course final grade is based on both the written and oral reports and presentations.

In the BUV project these guideline were followed. During the final stages of the course the students were required to do testing and validation of their vehicle under simulated Institute of Affordable Transportation conditions. During testing, fatigue cracks were observed in the welded corners of the U-member of the front end. The students were

instructed to do additional analysis of the components to determine the cause for the cracking. The component was analyzed using ANSYS® Finite Element Software. The results showed high stress in the right angle corners of the member. The weld was not modeled in this process so the high stress is a condition based only on geometry. The fact that the corner was welded magnified the problem. Gussets were added in order to eliminate the cracking problem. The part was reanalyzed and the results showed that the corner still contained high stress but the level was significantly reduced. The vehicle was modified and retested. No cracking was observed. It was recognized that the modified design is not optimum and that a redesign of the member would be necessary for a production vehicle. There was not sufficient time in the schedule to accomplish this design change prior to the competition. It was concluded that for the competition the design was acceptable with noted changes needed for future designs. The design, construction and testing phases were complete. Figure 3 below is a plot of static nodal stress from the FEA analysis showing the high stress condition on the inside corner of the U-member.

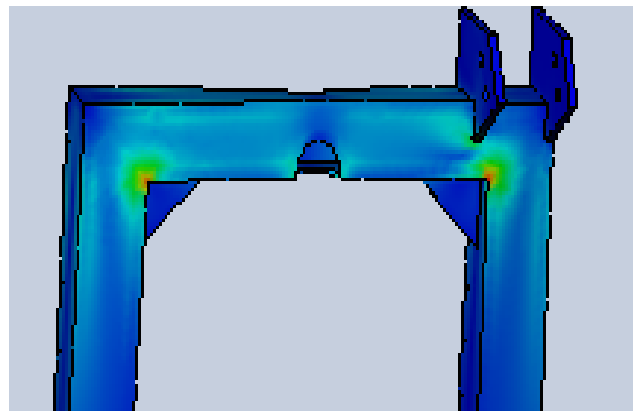


Figure 3 ANSYS® FEA of the welded corners showing the location of the high stress areas (orange). New gussets are shown in this drawing.

Senior Design Presentation day was April 28, 2005. The BUV senior design team's documents and presentations were both excellent. They were judged by a group of outside faculty and industry professionals in twelve different areas which included objective, quality of analysis, literature research, progression of the project, group synthesis and future work. The rating for the BUV design team was a 3.79 out a possible 4.0. Their table top display was well received and rides in the vehicle were given to faculty, staff and guests.

IAT COMPETITION

One last test remained for this team. On Friday April 29, 2005, they loaded the BUV and headed for Indianapolis, IN, for the Institute of Affordable Transportation. Inspection and check-in were held on Friday afternoon. The vehicle was in compliance in all categories.

On Saturday April 30, 2005, the all-day competition was held. The competition included the following tasks:

Endurance test (30 minutes)	Acceleration test (timed)
Mud Pit crossing	Agility test (timed)
Hill climb	Swamp crossing
Obstacle course	Oral presentation
Static pull	

A total of thirteen universities competed and the Miami BUV team placed first overall with a total score of 80.96. The next closest competitor was IUPUI with a total score of 77.82. The vehicle and team were the class of the field in both performance and looks. Figure 4 below shows the finished vehicle in competition



Figure 4 Competition photo of the mud pit crossing in Indianapolis, IN

SUMMARY AND CONCLUSIONS

In summary, this project was the ultimate model from many points of view. This project required the students to think and design in critical engineering terms, and also required that they find funding, build their design, manage a budget, and finally compete against other designers. This was a very meaningful and real-world experience for graduating Engineering Technology students. It is recommended that other Engineering and Engineering Technology programs consider a winning model such as the one described.

In developing and evaluating this teaching model [6] several critical elements were identified. They are summarized below:

- Integration of a Project Management (PM) course, skills and tools into the Senior Design course sequence.
- Early formation of project teams and careful selection of team members (should occur in the PM course).
- Early development of project proposals (should begin in the PM course).
- Proposal must be a contract among the students, faculty and support company.
- Development of a somewhat structured model for students to follow including key milestones, expectations and grading process.
- Inclusion of brainstorming design, construction, proof testing and a comparison to traditional or other similar designs.
- Required inclusion of design rigor for key components using skills developed in engineering courses.
- Students must accept responsibility for the project and should be required to work on their own as much as possible.
- Projects must be real-world projects done in conjunction with outside companies as much as possible.
- Projects in which the students can enter a design competition are strongly recommended.
- The IAT competition time line and milestones required students to work toward a realistic deadline which was an excellent real-world experience.

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- [1] D. Acheson, V. Yasinskiy, A Collaborative International Humanitarian Project in Engineering Education, Proceedings: The 6th International Conference on Engineering Design and Automation, 2002
- [2] Harvard Business School, Soldiers Field, Boston, Massachusetts 02163, <http://www.hbsp.harvard.edu>
- [3] “Build UrbaSport-A Car for All Reasons”, Mechanix Illustrated, Feb 1980
- [4] Robert Q. Riley, “Transportation Challenges of the 21st Century”, Museum of Modern Art, New York, NY, September 7, 1999

- [5] Robert Q. Riley, "Transportation 2000: Options for a New Millennium", Northwest Alternative Fuels and Transportation Conference, Portland, Oregon, April 20, 2000
- [6] Angelo, T.A. and Cross, K.P.; *Classroom Assessment Techniques* 2nd edition; Jossey-Bass: San Francisco, CA; 1993

AUTHOR BIOGRAPHICAL SKETCH

Gary Drigel is an Assistant Professor in the Engineering Technology Department at Miami University (Ohio). He received his Bachelor of Science Degree (1973) and Masters Degree (1980) in Metallurgical Engineering from the University of Cincinnati. He has also completed all his course work and part of his thesis work for a Ph.D. in Materials Engineering at UC. Gary is a Registered Professional Engineer in the State of Ohio. He has 30+ years of engineering and research experience gained at Armco Research and Technology in Middletown, Ohio and has been a professor at Miami University for 5 years. He can be reached at drigelgs@muohio.edu, Miami University, 4200 East University Blvd., Middletown, OH 45042.

APPENDICES

APPENDIX I

Harvard Business School ⁽¹⁾ (HBS) and other case studies list

- "The Case of the Machinist's Mutiny"*, W. Bruce Chew, Harvard Business Review Case 90602
- "Geartrain international: Medina, Ohio"*, Jack R Meredith, Prentice Hall
- "Oilwell Cable Company"*, Jack R Meredith, Prentice Hall
- "The Bowling 767: From concept to Production (A) and (B)"*, Harvard Business School Case 9-688-040 and 9-688-041
- "Columbia's Final Mission"*, Harvard Business School Case 9-305-032
- "Transformation at Ford"*, Harvard Business School Case 9-390-083
- "Final Voyage of the Challenger"* Harvard Business School Case 9-671-037
- "GM Powertrain"*, Harvard Business School Case 9-698-008
- "Adam Aircraft"*, Harvard Business School Case BAD010
- "Xerox and Fuji Xerox"*, Harvard Business School Case 9-391-156
- "Toyota Motor Manufacturing, U.S.A., Inc."*, Harvard Business School Case 9-693-019
- "Goodyear: The Aquatred Launch"*, Harvard Business School Case 9-500-039
- "Competitive Information Policy at Pratt & Whitney"*, Harvard Business School Case 9-394-154
- "Turner Construction Company: Project Management Control Systems"*, Harvard Business School Case 9-190-128
- "Johnson controls, Automotive Systems Group: Georgetown, Kentucky Plant"*, Harvard Business School Case 9-693-086
- "Navistar International"*, Harvard Business School Case 9-295-030

APPENDIX II
Gantt chart for BUV project created in Microsoft Project®

