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A Capstone Senior Engineering Design Course: A Project Case Study and Its Subsequent History

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I. Introduction

A senior engineering design course can be used to develop ties with industry while giving students a taste of real-life project engineering. The engineering and technology curricula at Lake Superior State University (LSSU) incorporate a two-semester, multidisciplinary capstone senior design course in which students participate in projects funded by local or regional industries. As such, the university must balance the needs of the funding company with the realities of teaching project engineering to students who may never have been involved in a "real" engineering project before. The funding companies expect and deserve a quality project and the university must provide students with a major design experience subject to realistic constraints that can be monitored and measured. Often, too, the students are more likely to remember and learn from a situation in which things goes wrong instead of a situation in which everything goes well.

This paper discusses one of LSSU's recent senior projects and the difficulties encountered both during and after its implementation. Continental Teves, Inc. (CTI), a manufacturer of electronic chassis systems (including Anti-lock Brake Systems and Traction Control Systems), approached LSSU to design, build, and test a surface friction tester. Aided by the engineering faculty and several industrial contacts from CTI, a team of six students implemented the project during a two-semester period. Along the way, they encountered many challenges, both expected and unexpected. Inadequate project planning and delivery delays resulted in the final product being delivered two weeks late, with only the most cursory of testing completed.

The surface friction tester delivered to CTI was successful in obtaining reliable friction coefficients when measured against other existing surface friction testers, such as that used by Continental General Tire Company. Significant problems existed with the tester, including control system limitations – most importantly the difficulty in maintaining a preset downward force on the test tire. In addition, some of the components were less durable than expected and failed prematurely. Finally, the tester exhibited a resonance problem that had not been anticipated. LSSU faculty and CTI engineers substantially redesigned the tester to correct the problems discovered and to upgrade the friction tester capabilities. LSSU and CTI have continued to co-operate on subsequent senior design projects.

LSSU evaluates the results of this and other senior design projects to improve the course and better achieve university goals, to aid students in timely completion of their projects, and to assure that the industrial partners are satisfied. The need for improvement in three main areas became clear after the 1998-99 school year. First, improvements were made in the integration of time management skills and assignments. Next, a greater emphasis has been placed on effective design reviews. Finally, the faculty members have begun to implement tools to aid in team formation, such as thinking preference styles. In hindsight, all six members of the CTI project team may have lacked strength in organizational and sequential thinking. LSSU now includes some cursory thinking preference testing to improve team formation in the future.

II. LSSU's Capstone Senior Engineering Design Course

LSSU is Michigan's smallest public institution of higher learning, with an overall enrollment of approximately 3200 students. LSSU offers Computer Engineering, Electrical Engineering, Mechanical Engineering, and Manufacturing Engineering Technology Bachelor of Science degrees to a relatively small undergraduate population of 300. Upon graduation, most students gain employment as engineers in regional automotive industries, automotive component supply companies, or in other manufacturing industries. LSSU uses its Senior Engineering Design Course as a bridge between the students' university education and their subsequent employment situations. As a result, there is a *significant* emphasis on providing a real-life engineering project experience that involves inter-disciplinary student teams[1,2].

The Senior Engineering Design Course consists of two back-to-back, three-credit courses, generally taken by the students in the fall and spring of their senior year. This course sequence is required for each BS degree offered by the School of Engineering and Technology. The course is administered by a faculty coordinator and is team-taught by as many as a dozen other faculty (the Senior Projects Faculty Board). Faculty members give lectures on specific areas of project engineering in which they have expertise while others are also given the responsibility of being a faculty advisor to one of the projects.

The two-course sequence has a dual track: students are taught general project management concepts at the same time that they've been charged to execute an engineering project. Efforts are made to integrate the "course" work with the "project" work. For instance, on the "course" side, students have assignments in creative thinking, research, time management, business memoranda, and project presentations - each of which are used to guide the students in their efforts on the "project" side of the course. The value of using "real" projects cannot be under-emphasized; the difference between a classroom exercise and an *industry* project is analogous in sports to the difference between practice drills and playing in the game[3].

The faculty coordinator solicits potential senior projects during the summer months. Prior to the start of the fall semester, the Senior Projects Faculty Board meets to discuss and screen the potential projects. The criteria used by LSSU to screen the projects are similar to those used at other institutions[4]. First, the project should be a meaningful industrial project. It should be more than a design exercise or a compilation of data. It should have the potential for benefiting the sponsoring company, adding something of real value when completed. Second, completion of the project should be readily possible in an eight to nine month period (the duration of the fall and spring semesters). There should a reasonable expectation of a successful project outcome, as contrasted with a report outlining why the project was not feasible.

After determining the most promising potential projects, the Senior Projects Faculty Board begins matching students and faculty advisors to the potential projects. The students are placed into multidisciplinary teams of four to eight students, team size being dependent upon on the magnitude of the project and the perceived strengths and skill levels of the students available. LSSU attempts to complete project screening and initial team formation before the start of the fall semester. Obtaining projects from sponsoring companies is germane to the success of the program.

III. LSSU's Industrial Advisory Board

Most of the ideas for projects are obtained from members of LSSU's Industrial Advisory Board (IAB). The IAB is comprised of professional men and women in engineering positions who actively participate in the development of LSSU's engineering and engineering technology programs, faculty members and students. The IAB presently has 33 members and has been active at LSSU since its inception in 1985.

The IAB has not only advised the administrators and faculty on engineering curriculum introductions and revisions, but has also provided over 80 employment opportunities and sponsored over 20 senior design projects in the past five years. Each of these projects fulfilled an industrial need. None of the projects were "industrial simulations." Several projects yielded test and process verification/implementation data. Others have produced manufacturing and/or test equipment and software worth millions of dollars. Some of these projects have included: an end-of-line parking brake tester, a paper bale handling system, an automotive airbag housing verification system, a power outage reporting system, and a gear shifter durability tester.

The IAB has provided approximately $1,000,000 of financial support not only for these senior projects but also to the School of Engineering & Technology for its support of the projects. Additional support such as project management, technical, software, material, and fabrication labor has also been provided.

IV. The Surface Friction Tester Project

During late summer of 1998, LSSU received a senior project proposal from CTI; to have a team of students design, construct and test a tire/surface friction tester. This surface friction tester would be used to measure the friction characteristics between various tires and road surfaces at one of CTI's product testing and development facilities. Although other friction testers were commercially available at the time, CTI desired a custom tester that would correct existing problems and incorporate more features than commercially available models. CTI's test facilities are located 20 miles from the LSSU campus.

CTI was aware of a commercially available tester for $200,000 that consisted of a fully instrumented tow vehicle and single axle test trailer. CTI desired a less expensive tester that could be towed by any number of different tow vehicles, accommodate a variety of test tires, use CTI software, and provide a varying, rather than static, load to the test tire. CTI proposed a $70,000 budget for the project.

The Senior Project Faculty Board accepted CTI's project proposal and formed a six-member, multidisciplinary student team. The team consisted of one mechanical engineering student; one mechanical engineering technology student; two manufacturing engineering technology students; one electrical engineering student; and one electrical engineering technology student. The Senior Projects Faculty Board believed that all six were solid performers who were capable of completing the project. The mechanical engineering student was an older, "non-traditional" student with work experience who was expected to take an ownership interest and leadership role in the project.

During the fall semester, the team performed adequately on early "course" and "project" assignments. The team did a thorough job of researching and analyzing designs for the trailer, comparing single axle designs with double axle designs. The team made a well-supported proposal for a dual axle design, which was accepted by CTI. The team also did a thorough job of determining the best location on the trailer for the test tire. Again, after a well-supported presentation by the team, the proposed location of the test tire (between the two axles, rather than along one of the axles) was accepted by CTI. The team researched, specified and ordered the longest lead-time item, a bi-axial force transducer, before the end of the fall semester. The trailer was designed and drawn. Fabrication of the trailer at CTI's facility was scheduled to begin over the semester break. There were no serious personality conflicts on the team and assignments were being completed in a timely manner. One of the students took an ownership interest in the design and construction of the trailer itself and another with designing a control system for the hydraulic piston-actuated test tire.

At the beginning of the spring semester, however, problems began to arise within the team. Although the work on the trailer was proceeding on schedule, the control system had not been designed or even fully specified. The student tasked with that portion of the project had done very little, which had not been discovered by the others. At a team design review in early January, it became apparent that no work on the control requirements for the hydraulic test arm had occurred and, moreover, no one had even a cursory understanding of the requirements for the control system. CTI personnel provided technical assistance to the team and explained the control process, but no one on the team understood the importance of the control system or the difficulty that might ensue in obtaining its components and putting it all together. By mid-February, the control system was still not designed and it became apparent to the Senior Projects Faculty Board that the team would have trouble completing the project by the end of the semester. Personality conflicts arose, also. The team's older student, rather than providing leadership, proved to be a loner who preferred to work independently of the others. When all six students were together, this older student consistently criticized the others and was the source of a lot of negativity.

As the spring semester progressed, it became evident that a detailed design of the control system could not be completed in the time remaining. The most promising solution found by the students was to purchase a pre-packaged control system from a company specializing in such designs. Although purchase of the pre-packaged system afforded the team the quickest delivery, it reduced the team's ability to specify individual components. Moreover, even with expedited delivery, the control package was scheduled to arrive the week after graduation, necessitating that the students return after graduation to finish the project. Needless to say, the students were dismayed by this prospect.

LSSU's position is that the student teams will do whatever it takes to complete their projects and provide the sponsoring companies with completed work products. The students learn that "walking away from the project" is not an option. Ultimately, the CTI student team finished installing the control package and calibrating the surface friction tester two weeks after graduation. Only the most cursory of testing was conducted, but the team delivered a functioning surface friction tester, see Figure 1 below, to CTI that cost well under the $70,000 allotted for it. The surface friction tester obtained reliable friction coefficients when measured against other existing surface friction testers, such as that used by Continental General Tire Company.

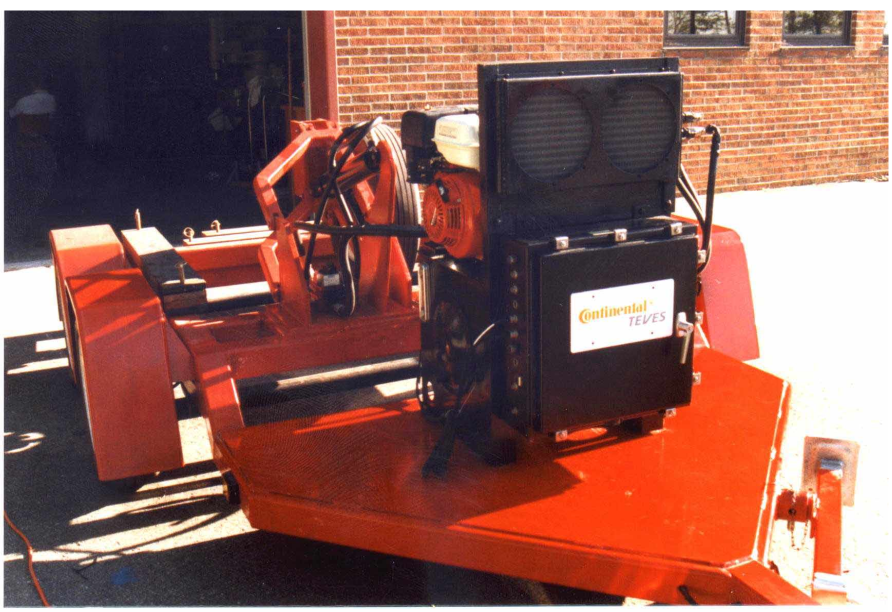

Figure 1: Trailer Completed by the 1998-1999 LSSU Student Team (May, 1999)

V. Subsequent Modifications to the Tester

After taking delivery of the tester in spring 1999, CTI began to use it at its product development and testing center in Brimley MI. CTI soon found that the tester did not perform as well as desired. Three main areas of concern existed with the tester. First, the trailer exhibited a resonance or oscillation problem in the tire normal load that had not been anticipated. Second, CTI desired additional capabilities (adding a slip angle to the test tire, for instance) that weren't encompassed by the original design. Finally, operation of the tester was cumbersome; CTI wanted the tester to be simpler and more user-friendly. Other problems included control system limitations, difficulty maintaining a preset tire load, and premature failure of some components that were not as durable as expected.

CTI approached LSSU in early 2000 to assist with a redesign of the tester to address the issues stated above. This subsequent partnering between CTI and LSSU involved the hiring of a mechanical engineering faculty member, LSSU's ME laboratory engineer, and several students, as well as the temporary use of LSSU's Mechanical Engineering Laboratory shop to perform the modifications. The redesign, shown in Figure 2 below, resulted in approximately 700 man-hours of faculty time, over 100 man-hours of lab engineer time, and over 100 man-hours of student time.

Figure 2: Trailer Modified during Summer 2000 (March, 2001)

Even after the redesign and modification by LSSU and CTI, there are still improvements to be made to the tester. Continued engineering effort is needed to decrease the deflection of the test wheel when subjected to high vertical and horizontal loads. Effort is also needed to verify the additional testing capabilities for wheel side-slip. Finally, effort will also be needed to make the new testing more user-friendly.

As a result, it is easy to see that the CTI project was a complex project, not a "cookie cutter" design. There are no surface friction testers in existence with the capabilities of the CTI tester. For this reason, the surface friction tester was more of a development project than was initially expected, requiring a complete change in philosophy of how to apply a load to a test tire (static versus dynamic, dead weight versus hydraulic cylinder). True development projects require significant time, money and resources to reach a successful conclusion, and need to be viewed in a different light than a typical design and build of previous or slightly modified systems. Development projects should expect setbacks during the execution, but this should be seen not as a failure but a learning of what won't work or what sub-problems must be solved. In the evolutionary process of development, all learning needs to be viewed as a step towards the final solution.

The LSSU Senior Projects Faculty Board underestimated the developmental extent of this project, contributing to the difficulties that the students experienced. CTI underestimated the actual amount of engineering and cost necessary to properly develop the tester. Despite the difficulties, CTI has continued to work with LSSU - not only in its re-partnering on the tester project, but also by providing one or two senior project proposals to LSSU each subsequent year, and hiring LSSU graduates.

VI. Course Improvements

Industry support, such as LSSU receives from CTI and other companies active on LSSU's Industrial Advisory Board, is essential for the continued success of the senior engineering design project course sequence. As a result, LSSU is continuously striving to improve the course and the method of teaching it. Several areas of improvement were needed to address the problems that arose during the surface friction tester project. Changes were made to better integrate time management and timeline assignments into the syllabus; more emphasis was placed on team design reviews (with examples given); and improvements to the process of team formation were initiated.

On this project, the team successfully completed a timeline assignment early in the fall semester. Thereafter, the team failed to continue to implement time management techniques during the remainder of the project. This seeming "disconnect" between the "course" work and the "project" work continues to be a concern to the faculty at LSSU. Despite insuring that "course" assignments are directly pertinent to the team's project, there is sometimes difficulty in integrating the assignments in such a way that the students perceive their value to the ongoing project. In subsequent school years, there has been an increased emphasis on time management skills and the project timeline is now consulted at each weekly team meeting, so that students will not cease updating the timeline as soon as the "assignment" is done. Monitoring of the team timeline at weekly team-advisor meetings can prove helpful in spotting a complete lack of progress on an area of importance, such as the control system on the CTI surface friction tester project.

Another area of improvement to the course has occurred in the area of design reviews. In fall 1998, the surface friction tester team successfully completed a design review pertaining to the design of the trailer. The team's next design review, regarding the control system, occurred early in the spring semester - too late to enable CTI and the

Senior Projects Faculty Board to determine the team's failure to design a control system. If that design review had also occurred in the fall, the team may have been able to complete the project on time, rather than during the summer after graduation. As a result, LSSU now has an increased emphasis on early design reviews and has implemented an extensive system of monitoring team progress. The major purpose for design reviews is to communicate proposed designs and plans, to solicit input on the designs and plans, and to finalize design issues. Two or three hour design reviews, attended by both faculty and representatives of the sponsoring company, provide the teams with intense, useful input into the project. This increased focus on design reviews seems to have aided subsequent student teams in successful completion of their projects.

One final area of emphasis bears mentioning. LSSU has added an increased level of scrutiny to team formation. The formation of productive teams is a critical and difficult task. In the spring semester preceding their enrollment in the senior projects course sequence, the Senior Projects Faculty Board now administers a "thinking preference survey" to the students. The purpose of the thinking-preference questionnaire is to ascertain the students' propensity for the following four thinking styles: (1) analytical and logical, (2) planning and organizational, (3) interpersonal and intuitive, and (4) conceptual and holistic. In hindsight, it is believed that none of the students on the surface friction tester project had a strong dominance in planning and organizational skills. This may have contributed to the team's failure to complete the project on time, but this is only conjectural since no qualitative assessment of those students' thinking preferences are available.

Recognizing that students often demonstrate clear thinking preferences, the Senior Projects Faculty Board now performs a cursory screening of the students' thinking preferences, using a format patterned after the Hermann Brain Dominance Instrument[5]. The students are divided into teams based upon the results of the questionnaire, with the intention of creating "whole-brain" teams (teams of students that exhibited all four thinking styles). This procedure has been helpful in avoiding teams that lack some fundamental component of project execution.

These improvements in the course have and continue to result in better and more successful senior projects where university and industry pair up for the benefit of both parties. However, the university must continue to strive to identify which proposed projects are truly developmental. For developmental projects, it is important that the university and industry are calibrated on the potential outcomes and problems associated with development, recognizing that new knowledge gain is often expensive and unpredictable.

VII. Conclusion

The design and construction of an innovative and specialized surface friction tester provided a two-semester engineering design project for six students at Lake Superior State University. The implementation of the project resulted in areas of successful as well as inadequate performance, but ultimately resulted in a functioning surface friction tester for Continental Teves, Inc., the project's sponsoring company. Subsequent redesign and modification to the surface friction tester demonstrates that the project was a complex developmental-type project, rather than a "cookie cutter" design-and-build assignment. Both students and faculty learned from the experience, and LSSU and CTI have continued to team on subsequent senior engineering projects for LSSU's engineering students.

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