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RECASTING INDUSTRIAL PROBLEMS FOR USE IN AN ACADEMIC SETTING

by

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Summary:

Most industrial problems must be recast for use in undergraduate courses. Recasting often includes problem simplification and adaptation to the educational objectives of the course. Requirements for disclosure of proprietary or trade secret information must be avoided. A number of examples are provided in the fields of forest, agricultural and horticultural engineering.

Keywords: **Education, design, problem solving**

Recasting Industrial Problems for Use in an Academic Setting
James H. Dooley, PE

During the past twenty-five years the author provided dozens of industry-based engineering and design problems for use in undergraduate and graduate academic programs. This paper presents a discussion of how industial problems can be effectively translated, or recast into homework assignments, team problems, and capstone design projects. A set of actual problems as delivered to students is included as an appendix.

Professors love to receive current problems from industry. Industrial problems are assigned as homework, term projects and final exam problems. Faculty members report that "real world" problems generate more enthusiastic classroom discussions than textbook problems. Students have an opportunity to learn more about what professional engineers really do in the industries they might apply to after graduation.

Benefits of Providing Industrial Problems

Among the complaints most often lodged against the American engineering education system are: 1) new graduates cannot solve "real-world" problems typical of their first job assignment, and 2) prospective new-hires do not understand the companies to which they are applying for jobs. Through direct participation in the undergraduate and graduate educational experience, employers can ensure that students are exposed to real problems relevant to their industry and gain some appreciation of the business of the sponsoring firm. Interaction with students provides visibility for the sponsoring firm, as well as an early opportunity to assess potential summer-hires and recruiting prospects. If the sponsor is neither a "name" company nor in a popular industry, the visibility afforded by project involvement can be instrumental in attracting applicants from among the top students in a program.

Student-proposed solutions to "unsolvable" industrial problems can be the source of breakthrough thinking. Student designers and teams often exhibit a creative naiveté that can develop innovative solutions to long-standing and previously unsolved problems. Rarely in my experience has a student design or problem solution been able to be placed directly into use. However, almost always the solutions we received stimulated new lines of thinking or improved problem clarity. Where else can you tap the creative energy of five, ten or more people for free or near-free?

Student projects may be developed in an exploratory area that your firm would like to get into, but does not choose to commit internal resources to. Such projects include technology assessment, experimental application of a new analytical tool, evaluation of new materials and application of an existing product to a new use.

The benefits of long-term association with an undergraduate program are less tangible, but the author has found them extremely valuable. In one case we provided problems that put us in contact with the same group of students at the freshman, junior and senior year. We went on to partially support one student to pursue a master's degree to continue working on a solution to his undergraduate senior project. Ongoing contact with faculty members ensures their accommodation when you call for advice on a tough problem of your own.

Challenges

Problem complexity often needs to be "toned down" unless the course has a focus on problem solving. Few students have an ability to analyze complex problems and appropriately craft a crisp engineering problem statement. Although an experienced engineer might be comfortable with the horrendous complexity of a problem framed as "the machine makes too much noise" or "the shelf life is too short," typical undergraduates will spend the entire term in futility. The machine noise problem is better framed as either an acoustic analysis problem, a sound enclosure design problem, or a systems engineering problem. The shelf life problem might be recast as either a package design problem, environmental control problem, biological decay problem, or processing problem.

The educational value of the problem must be clear in the problem statement and associated dialog. Problems that appear to be "industrial welfare" and "undergraduate abuse" are a turn-off for both students and faculty members.

There has to be a learning experience. In many sponsoring companies, managers and problem owners may not be understanding when a problem is recast to meet educational objectives rather than pressures of the day in the firm.

The problem statement and expectations must be consistent with prerequisites and course plan. This concern is somewhat parallel with the previous challenge in that other members of the sponsoring firm may not appreciate that the students are freshmen, seniors or otherwise inexperienced. A problem contributed to an E100 - Introduction to XXX Engineering course needs to be cast such that it stimulates creative thinking, appreciation of the profession of engineering, and perhaps an appreciation that the core engineering courses are useful. A problem contributed to a mechanics of materials course, or professionalism and ethics course likewise need to be carefully developed. Such problem statement development takes time – more time than most people appreciate.

Project sponsors need to be accessible to the students for problem clarification, mid-project review and final report presentation. The academic calendar is extremely rigid and delays of just a few days can doom a project. Email and web communication is helping, but direct contact is just as important with student teams as it is with your own employees.

Product dissection and critical analysis is an "in thing" for engineering students to do at the moment. Product liability concerns need to be discussed and considered before giving student groups projects that involve probable assessment of product safety and usability. Student reports may be brought into a product liability case through discovery. Unlike internal reports, the company normally does not have the right to request that students reconsider their findings and/or issue a retraction. The consequences of student product evaluations may not be all negative. A company which quickly responds to discoveries made by external reviewers might be able to use the fact that the company encouraged external review and made aggressive corrections to their benefit.

In a similar vein student evaluations of current and prototype products may identify potential warranty problems. Student analysis may reveal unexpected weaknesses, novel methods for product misapplication, and other discoveries that were unlikely to be made by the sponsor's own staff.

Patent infringement risk is a two-edged challenge in student design problems. On the one hand many students are not taught to conduct patent searches and avoid unexpired patents. Since the United States does not have a research exemption, the company could be liable for claims of infringement if they experiment with or further develop infringing student designs. The receiving firm has a duty of due diligence to reasonably assure themselves that designs received from academic institutions do not violate the intellectual property rights of others.

Students and faculty members always seem to want access to trade secrets and other proprietary information as they pursue a problem provided by industry. It is this author's opinion that the educational mission of an institution is compromised when confidential agreements other expectations that students and teaching faculty will respect a company's proprietary information are imposed on an undergraduate project. There is an opportunity to help teach the concept of "need-to-know" when enforcing a restriction that no proprietary information be disclosed to students or faculty members. Students who successfully solve industrial problems without knowing "everything" are more likely to respect proprietary information when working for contractors and consultants after they enter full-time employment in industry.

The flip side of avoiding patent infringement is that student design teams may come up with patentable solutions to the problem you provide. The sponsor needs to prepare for such an event. If patents are the lifeblood of the sponsoring firm, then it should think long and hard before providing design and other problem solving projects. Analysis projects and manufacturing improvements are probably safe. Students rarely keep good records of inventorship. The institution may block attempts you may make to have the students involved in a sponsored project pre-assign inventions to the sponsor. It is not at all clear that the institution itself has any rights to inventions made by undergraduates when they are engaged in coursework. Students may make their first real invention and want to patent it themselves. They rarely follow through, but the possibility remains.

Recommended Approach to Working With Academic Institutions
When you consider the challenges facing someone in industry who wants to provide problem sets for academic use, it hardly seems worth the risk and effort. The author's experience suggests that problem formulation gets easier after the first few attempts, and the rewards make the effort worthwhile.

Interview the Course Supervisor or Faculty Member
1. What is the course objective?
2. Review a copy of the course syllabus and lesson plans
3. What are the educational outcomes the course should deliver?
4. What is the student competency level?
5. Are problems cast for 2.5 or 3.5 GPA students?
6. What are the prerequisites?
7. Who grades student work and reports? (Not the industrial cooperator, hopefully)
8. What is the expectation for attendance at presentations and reviews on campus?
9. Will the faculty member support field trips for students to visit the industrial site?
10. Discuss the nature of problems you face and those that might be relevant for use in the course.
11. Agree on a format for your initial problem abstract and information about the problem.

Provide the institution with:
1. Problem abstract, list of constraints and a background statement. Try to fit this on one side of one page of paper. This is the "teaser" that gets a team interested in your project.
2. Provide a video tape if possible of your operations, and the problem situation.
3. Offer to arrange a field visit to view the problem situation for the project team if your project is selected.
4. If the problem is amenable to making actual prototypes or concept models that requires consumables, offer to give each class a "grant-in-aid" in the amount of one hundred dollars or some other nominal amount.
5. Identify a "client" for each project team. The client contact person will be expected to answer phone and email requests for information, attend on-campus reviews and final reports, and generally participate in the design process.
6. Offer to host a presentation by the student team and supervising faculty member at the end of the project so there can be an on-site presentation and recognition event.

Expect the institution to:
1. Respect your need to protect proprietary information and exclude access to controlled parts of your operations.
2. Manage the student team and coach team members on appropriate ways to communicate with clients.
3. Provide interim reports and opportunities for mid-term adjustment of constraints.
4. A complete set of non-proprietary final reports, drawings, videos, and other materials developed by the students.

Examples of Recast Problems
What follows is a discussion of a number of example problems from the author's files. The actual problems are included as an appendix to this paper.

<u>Spar Milling Machine</u> – Provided to University of Washington ME capstone design proposal development course. This is an open-ended creative and mechanical design problem on how to make a giant pencil sharpener of sorts. How does one deal with variability of wood materials that are not straight, have knots and odd grain patterns?

<u>Zero-Deflection Rolls for Wallboard Delaminator</u> - Provided to University of Washington ME capstone design proposal development course. The problem would require high levels of creativity to devise a solution to a long-standing problem for our client company. There are a number of potential solutions in the literature and patent files that would need to be translated from steel and metals industry to our low-budget recycling problem with a more brittle material. The analysis of deflections is a classic mechanics problem that could be very complex or

solved via numerical analysis. This problem brings together information gathering, creativity, synthesis and analysis based upon core prerequisite courses.

Flexible Ankle-Supporting Boot – This is a classic bioengineering problem with commercial applications for students with entrepreneurial aspirations. Solution requires exploration of anatomy, injury mechanisms, workplace biomechanics and ergonomics, as well as the history of the shoe industry. There are as many business strategy questions as mechanics questions that constrain potential engineering solutions. A student team at the University of Washington is pursuing this problem.

Leave Tree Specifications – This problem was developed as a homework problem for seniors in a silvicultural engineering course. The format of the course was such that students were to behave as though they were employees of a fictitious forest engineering consulting company. The homework and term problems were delivered as written memos followed by discussion in a "staff meeting" during class time. This particular problem supports lessons on modeling growth, shape and strength of whole trees. This problem is current in industry and public forest agencies. Classical application of wind load models from highway signs and buildings will lead to tree diameter specifications that are implausible. The students will learn ways to modify available wind load models to fit live plants such as trees. Although this is a "simple" problem of a vertical cantilevered tapered beam, the students find the problem a major challenge to solve.

Tree Mass, Center of Mass, etc. – This is a real application of everything engineering students learn in mechanics of materials, statics and dynamics. A tree growth model can be built into a spreadsheet to solve the problem. Every engineering graduate should be able to solve this problem.

The five problems presented here were selected out of dozens that the author has developed or collected. These recent examples were created in collaboration between Silverbrook Limited and Dr. Jim Fridley at the University of Washington. The two approaches to problem presentation were set by the course supervisors.

Project Title: Spar Milling Machine
Project Contact: Jim Dooley, ELWd Systems, Federal Way
jdooley@seanet.com, 253-838-4759

Objective: Design complete device and prototype key components of a hydraulically powered machine to prepare the ends of wooden spars to be used in engineered fish habitat structures.

Background: The client has developed and filed for patent protection on a novel method of constructing large woody debris habitat structures from small-diameter logs. Key elements of the structures are spars that join pairs of logs. Spars are typically 18 – 48 inches long and made from 4-6 inch diameter rough logs with the bark intact. Each end of a spar must be milled to a round tenon 3 inches in diameter and variably from 3.5 to 8 inches long. Each tenon must be core drilled with a 1 inch diameter bore to a depth equal to 75% of the tenon length. Each tenon must also be cross cut so it can be spread by a tapered round wedge.

Spars are to be manufactured on a portable hydraulically powered machine center. The portable machine centers will be leased or sold to logging contractors throughout North America and will be used in open lots exposed to rain, dust and other difficult conditions. The spar making unit will be one of three machining systems on the portable machine center. Others will cut materials to length and bore the logs to fit the spars.

Currently, the spars are turned on a wood lathe and then bored and cross-cut in two additional operations. Spar making is the most-expensive and labor consuming operation in manufacturing engineered habitat structures.

Photos and models are available from the client.

Customer Expectations:
1. Spar making will be a one-person job.
2. Machine is robust enough for field operation and maintenance by logging mechanics.
3. Machine center is intrinsically safe in that it prevents entanglement, fails safe, and has zero potential energy when off.
4. Design is appropriate for a product that will have production runs of 10-20 units and total production life of approximately 150 units.

Technical Requirements:
Student design team must have a background in mechanics, mechanisms, hydraulic controls as well as design.


Project Title: Zero-Deflection Rolls for Wallboard Delaminator
Project Contact: Jim Dooley, GP Research, Federal Way
jdooley@seanet.com, 253-838-3496

Objective: Design and prototype a method to deliver uniform compression across the full width of a sheet of wallboard when using small-diameter rolls.

Background: A small company in British Columbia invented and patented a method to recycle waste gypsum wallboard (drywall). The method involves gently crushing the crystalline layer of gypsum just under the paper faces. When done correctly the paper peels free of the core and the core is left essentially intact. The preferred method of delamination is with a series of small diameter rolls that pinch the board as it travels through the delaminator. Each pair of rolls compresses the board only about 0.012 inches. We know that smaller diameter rolls are better than larger diameters, and would like to use rolls that are about 3.5 inches in diameter. The contact forces are about 25 pounds per inch of roll length for that diameter of roll. As the roll diameter increases the required contact force increases dramatically to achieve the required step per roll pair. A typical machine will have 12 pairs of rollers.

The scrap drywall ranges from 12 inches to 54 inches wide. Pieces are fed into the machine by hand from an infeed table where the material is oriented and singulated. Machine width capability should be 54 inches. The gap between rolls should be adjustable to accommodate all commercial drywall thickness Initial board thickness should be adjustable to fit board that is from 3/8 to 1 inch thickness.

Rudimentary deflection analysis will show that straight, unsupported rolls will deflect sufficiently that the center of the roll will not be in contact with the board. The client's organization has identified at least ten fundamentally different ways to address the deflection problem. None appears to be an ideal solution.

Customer Expectations:
1. Creative solutions are encouraged.
2. Because lots of rolls are involved in a delaminator machine cost is important.
3. Solutions fit the mechanical and technical capabilities of existing wallboard manufacturing plants.
4. Solutions can accommodate gypsum dust and residue buildup on the rolls.

Technical Requirements:
Student design team must have a background in mechanics, mechanisms and materials as well as design.

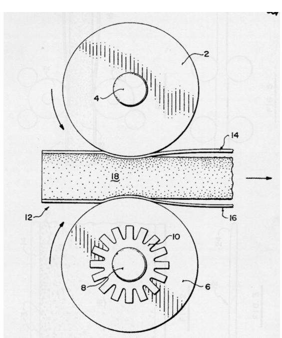


FIG. 1

Project Title: Flexible Ankle-Supporting Boot
Project Contact: Jim Dooley, Baetis Technology, Federal Way
jdooley@seanet.com, 253-838-4759

Objective: Design and prototype a logging boot upper that allows complete normal range of ankle motion, yet prevents over-rotation injuries.

Background: Ankle injuries are among the most frequent traumatic and chronic causes of workers compensation claims in the forestry, logging, wildland fire-fighting and similar occupations. Workers almost universally reject boot designs that are rigid as being uncomfortable and unsafe. Workers believe that high flexibility is necessary to allow the foot to set solidly on hillsides, logs, rocks and other surfaces. So-called “Technical,” or rigid boots cause the contact to be on an edge of the boot, resulting in slips and falls. Traditional leather boots are judged to be “too stiff” when new and generally require at least two months of use before they are “broken in.” However, broken in boots offer little ankle support. What is needed is a boot design that allows the full range of normal ankle motion, yet offers a high level of protection from ankle injuries.

The client has conducted a fairly extensive literature and patent search. Those materials will be available to the student team.

Customer Expectations:
1. Degree of flexibility is judged to be adequate by a panel of loggers and woodsworkers.
2. Retail pricing for the resulting boot with a Vibram™ sole in the range of $200 per pair.
3. Frequency of ankle injuries for workers wearing new design boots is reduced by ½ from current rates when boots are new and by greater than 1/3 for year-old boots.
4. Mechanical concepts involved in the new boot are adaptable to a variety of boot styles – caulk, lug sole, composition sole, etc.
5. Overall product execution (look and feel) has market appeal to loggers, woodsworkers, firefighters and corporate purchasing agents.

Technical Requirements:
Student design team must have a background in mechanics, mechanisms, materials and biomechanics as well as design.

FEs R Us Forest Engineers and Planners

Seattle, Washington

INTERNAL MEMORANDUM

DATE: October 16, 1996

FROM: Jim Dooley

TO: Silvicultural Design Team

SUBJ: **Leave Tree Specifications**

Our client is planning to clearcut harvest a fifty-year-old stand of Douglas-fir. They have decided to embrace the idea of leaving dominant trees to meet the regulation requiring six leave trees per acre. This site which is near the coast includes a knoll that is exposed to winds coming off the ocean, so the client is particularly concerned that the leave trees do not break or wind-throw.

When we write the harvest prescription that includes a requirement to leave six dominant trees per acre we need to also specify a minimum dbh to ensure they will not break in the wind. Our cruise reports indicate the site index is 110 and the dominant trees have a lower branch length of thirty feet. We will pay a penalty to the owner and the owner's fine from the regulatory agency if leave trees blow over or break off. Our general manager and the client have agreed on a design wind speed of 75 mph for trees with a crown ratio of 0.5.

At a team meeting the foresters proposed to survey clearcuts that have leave trees exposed to on-shore winds and measure the diameter of those standing vs. those broken and blown down. They estimate it will take six person weeks to do the survey and statistical analysis. A planner on the team suggests that the engineers should be able to calculate an acceptable answer in just a few hours. Since we have to issue the prescription by the end of next week, not in two months, the team leader decides to use an engineering calculation rather than a field survey.

The questions I have for the silvicultural engineers on our design team are:

1. What dbh (inches) should we set as the minimum for leave trees that are 100-110 feet tall?
2. How many trees should we leave to ensure there are six at the end of three years?
3. How much merchantable volume are we leaving behind in the leave trees? Express your answer in cunits (100 Ft^3.)

FEs R Us Forest Engineers and Planners

Seattle, Washington

INTERNAL MEMORANDUM

DATE: 22 October 1996

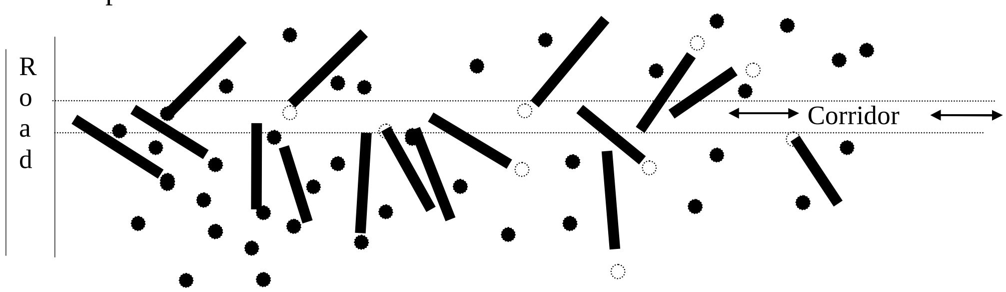
FROM: Jim Dooley

TO: Silvicultural Design Team

SUBJ: **Homework - Tree Mass, Center of Mass, Mass Moment of Inertia**

An inventor has contracted with us to provide important data and design guidance. The invention is a "shuttle forwarder" that will run up and down thinning corridors in commercial thinning operations and take felled logs out of the forest to a landing. The shuttle forwarder has a gripper on a boom that can reach sixteen feet from the centerline of the forwarder. The machine will pick up individual tree-length stems and place them in a bunk on the forwarder. We need to tell the inventor what kinds of forces to expect when the machine is working in a stand that used the Swedish herringbone method of felling.

The Swedish herringbone method of felling involves cutting all the trees in a ten foot wide corridor which runs at right angles to the road. Corridors are about two tree-heights apart. Trees between corridors are selectively felled so that either the top or but is near the corridor.



If we assume that the species is Douglas-fir, trees are cut to a four inch top, the site index is 120 and the stand age at time of thinning is about 30 years we should produce a fairly conservative recommendation.

Questions:
Week 1.

1. What is the expected mass of the individual trees?
1a. What mass would you use in design calculations?
2. What is the mass moment of inertia?
2a. What mass moment of inertia would you use in design calculations?
3. Where is the center of mass on the trees?
3a. What center of mass location would you use in design calculations?

Week 2.

4. What is the maximum acceleration the gripper can have when it picks up a tree by the four inch top?
5. What is the maximum acceleration the gripper can have when it picks up a tree by the butt?
6. If the gripper can power-draw stems so it can get a higher grip on the stem how does the allowable acceleration change as you move away from the top toward the butt? Bonus question: Sketch the motions of the stem as it is taken from the ground onto the forwarder bunk.