The Creation of a Cost Effective Intercollegiate Design Contest: The Human Powered Paper Vehicle Contest

Donald Richter & William Loendorf
Eastern Washington University
School of Computing and Engineering Sciences
Department of Engineering and Design

Keith Turpin
The Boeing Company

Abstract

Engineering Education should include the opportunity for students to apply the engineering skills they are acquiring in a practical application to reinforce and expand their learning process. Ideally this experience should also be designed to include team building and communication skills. One mechanism traditionally used in Engineering Education to accomplish this goal is a design contest involving teams from different colleges and universities.

However, there are limiting factors inherent in these design contests. The first is the cost of designing and building a device for the event. To field a competitive team, cost can easily range from hundreds to thousands of dollars for materials and travel expenses. This is a significant obstacle to participation for many schools, particularly with today's shrinking departmental budgets. In addition, due to this high cost, the college or university is usually limited to sponsoring one or at most two teams. This contributes to the second limiting factor of access and inclusiveness for students interested in participating. There is also a question on how freshman and sophomore students can contribute to the team or even become a team member. Due to the limited number of students that can participate on the "one" team, junior and senior engineering students are typically selected because they have completed more engineering courses. This does not help to promote the retention of freshman and sophomore students in the engineering disciplines. Rather the inclusion of beginning students would offer them a true practical engineering experience to keep them motivated and interested in completing their engineering education. But how can this dilemma be resolved?

Eastern Washington University has created a Human Powered Paper Vehicle (HPPV) Contest to meet these challenges in the confines of an intercollegiate design competition. This paper describes how the contest has solved both the cost issue as well as participation by freshman and sophomore engineering students. In addition, the history, rules, results, and lessons learned from hosting this annual event are discussed. The success of the HPPV contest in meeting the above

challenges has led the American Society of Mechanical Engineers (ASME) to adopt the contest as a voluntary regional event.

Introduction

Each year, Eastern Washington University (EWU) hosts the annual Intercollegiate Human Powered Paper Vehicle (HPPV) Engineering Competition. Typically colleges and universities from Washington, Idaho and Oregon participate in this event. This engineering competition inspires students, challenges their engineering skill and creativity, and provides a format that limits the amount of money needed to field a competitive team [1, 2, 3, 4]. There is no cost to enter the competition. The only costs involved are for basic materials, which are generally very low, and time.

The basic concept is to construct a human powered vehicle out of 90% paper products (by weight). The remaining 10% can be any type of material and is limited only by the imagination of the designers. There are two parts to the overall competition, the first tests the vehicle's performance while the second gauges the team's presentation skills. These events are treated as separate portions of the overall competition, although participation in both events is required. Participation in this engineering design project helps to develop student excellence in teamwork, communication, and creative problem solving [5, 6, 7].

Awards are presented for both categories: vehicle performance and team presentation. The first place team in each category receives a trophy for the college or university and medallions for each team member. The second place teams receive a plaque for the college or university and medallions for each team member. In addition, plaques are awarded to the schools and medallions are awarded to team members for "the most innovative design" and "the best team spirit." In addition each team member receives a commemorative HPPV competition t-shirt.

The following quote is from a team's winning presentation:

> When you are faced with a set of specific guidelines, how do you view those rules? Are they constraints or challenges? Are they limits or opportunities? Do you view cardboard as a flimsy, useless paper product only good for boxes or is it a powerful tool that demonstrates the challenges that students will face in the workforce after graduation?

Colleges and universities are guaranteed entries for two teams with additional teams allowed as space permits. This competition is open to all students regardless of major or academic rank. It presents a great opportunity to challenge the creativity and ingenuity of the students while introducing and reinforcing engineering and design concepts [8, 9]. For many student competitors it becomes one of their first true engineering projects that both supports and enhances their studies.

History

The Human Powered Paper Vehicle competition began in 1997 and was the creation of Boeing Project Coordinator and former Eastern Washington University student Keith Turpin. Only four teams competed that year, but the popularity of this unique engineering contest has grown in each successive year.

The objectives of the competition were intended to address the following:

- The task had to be achievable.
- The cost of fielding a team must be very low to not present a barrier for entry.
- The project could utilize the skills of both novice and advanced students.
- A team activity that would help develop team-working skills and aid student's in understanding the importance of cooperation and compromise.
- It had to present an engineering oriented challenge that would require creativity, vision, and problem solving.
- It must present students with a challenge that would help them understand the differences between a good design in theory and a design that can be actually built to meet the functional requirements.
- It must place an equal weight on the team's ability to present their ideas. In industry, having a great idea is often not enough. Typically others must be convinced that the project is worth investing in or else it may never be built.
- It had to be structured with well-defined rules that could be clearly understood.
- It must have academic merit and provide both faculty members and students an opportunity to utilize this activity in course work. Typically this is realized in a freshman engineering course.
- It had to be fun.

The amount of money required by a team or school to build a competitive vehicle is very low, which addresses the issue of cost. In the past, teams have been very creative in their efforts to acquire raw materials. They have used recycled cardboard boxes and paper tubing used to hold carpet or laminate flooring rolls. They have also contacted local packaging, paper, or concrete companies to get materials donated that included corrugated cardboard, honeycomb board, and sona tube concrete forms. Non-paper materials are often salvaged parts or low cost components like metal tubing, bars, PVC pipe, wood, or used bicycle parts. Finally, glue and tape costs are usually quite low.

The competition addresses the issue of participation by balancing the benefits of engineering experience and team diversity. More advanced students may be able to contribute in the design process by helping to ensure that sufficient design safety margins are used, that principles of machine design and ergonomics are employed, or making sure that design requirements are properly defined. They may also be able to utilize advanced drafting and design techniques along with software models to develop the design before it is built. Students with less engineering experience can also be valuable contributors to the creative design process, since paper is not normally used in this manner. In addition, neither advanced nor beginning students can turn to a textbook for possible design suggestions or solutions. As a result, all students can contribute to the vehicle construction process and development of the presentation.

In developing the original competition, extensive research was done on existing engineering competitions, class projects, and industry sponsored events. The goal was to find an existing concept that could be further refined and developed to meet all of the competition objectives. Building a paper vehicle as an engineering event had been utilized to one degree or another at both the college and K-12 education levels. For example, Stanford University used a similar competition as a class project for its Mechatronic Systems Design and Methodology course and

Georgia Tech's Institute of Paper Science and Technology (IPST) has proposed paper vehicle competitions. These ideas served as the foundation on which this competition was built.

The Annual Human Powered Paper Vehicle Competition takes place in early spring on the campus of Eastern Washington University in Cheney, Washington. The success of the HPPV contest in meeting the needs for an inexpensive engineering design competition that students can participate in regardless of academic rank has led the American Society of Mechanical Engineers (ASME) to adopt the contest as a voluntary regional event.

The Competition

Vehicle Design, Analysis, and Construction

All of the analysis, design, and construction of the vehicle must be completed solely by students currently enrolled at the sponsoring college or university. In addition, each student's name must appear on the team's roster. No outside assistance of any type is allowed.

At least 90% of the vehicle (by weight) must be made from paper or paper products. Adhesive weight (tape, glue, etc.) used on the vehicle is not counted toward non-paper weight. However, glues are to be used solely in an adhesive capacity (i.e. parts molded from glue must be counted as non-paper material weight). The vehicle's total weight may not exceed 75 pounds.

An official Non-paper Materials Log Sheet is also required and must be completed and submitted at the time of on-site registration. It must contain a complete description of all non-paper components, their uses, and weights (adhesives do not need to be listed). In addition, all non-paper materials used in the construction of the team's vehicle must be weighed and verified by a member of the school's faculty. A non-faculty representative may be appointed for this task, as long that person is not a member of any team. The representative or faculty member's name, signature and contact phone number and that of any appointed weight checkers must be included with the non-paper log sheet.

Any and all types of non-functional weight are not allowed. The weight of all paper must contribute to the useful operation of the vehicle. Paper may not be added for the sole purpose of offsetting non-paper weight.

A vehicle that was previously entered in the competition cannot be reentered. No parts may be used from vehicles that have previously completed the racecourse. Vehicles, which did not complete the racecourse due to an operational or structural failure, may be reentered or parts from that vehicle may be reused for one additional competition.

Tape and high strength fiber cloth can also be used, however there are some restrictions. Only those brands and grades of tape specifically listed below may be used without counting as non-paper weight:

- Packaging Tape
  - United Tape Company Clear Carton Sealing Tape in either Standard or Commercial Grade
  - Scotch Super Strength Packaging Tape

- Duct Tape
  - United Tape Co. Standard or Contractor's Grade Duct Tape
  - Scotch/3M High Performance Cloth Duct Tape
- Standard Masking Tape is also acceptable**.**

Additional tapes that are not specifically listed and all forms High Strength Fiber Cloth may be used only for joint re-enforcement. However, they must be weighed and listed in the Non-paper Materials Log Sheet and may not be used for structural enhancement. This includes, but is not limited to the following examples:

- Strapping tape,
- Fiber reinforced tape,
- Poly tape,
- Carbon fiber,
- Fiberglass, and
- Kevlar cloths.

The vehicles may be painted as long as the paint does not contribute to its performance.

Functional Requirements

The functional requirements for the competition are:

- Only human power may be used to drive the vehicle.
- The rider is not allowed to physically touch the ground during the competition, either with his/her feet or with any other part of his/her body. Each infraction will result in a performance penalty equal to 10% of the total course time.
- The vehicle must be powered by three different riders and be able to support a minimum rider weight of 120 pounds.
- The vehicle must accommodate both steering and braking.
- The vehicle must be capable of completing the course including the Ramp Bridge, which incorporates a 10.6° incline and decline.
- The weight of the vehicle may not exceed 75 pounds.

Performance Penalties:

No vehicle can exceed the 10% non-paper weight limit by more than 0.50 pounds. The extra weight allowance (0.50 pounds) is tolerated to compensate for mistakes in weight calculations that are not discovered until after the vehicle's final assembly. Any vehicle with a non-paper weight greater than 10% plus 0.50 pounds will be disqualified from the performance portion of the event.

Vehicles exceeding the 10% limit by 0.50 pounds or less will receive a performance time penalty. For each 0.10 pound that a vehicle exceeds the allowable 10% non-paper weight, a 5% time penalty will be assessed against the vehicle's performance.

For example: If a vehicle weighs 65 pounds and has non-paper weight totaling 6.8 pounds, it has exceeded its 10% limit by 0.30 pounds. Therefore, a penalty of 15% will be added to the vehicle's actual race time. If the vehicle completed the course in 180 seconds, its final race time would equal 180 x 1.15 or 207 seconds.

Energy Storage

No energy storage devices of any type can be utilized on the competing vehicle. This includes but is not limited to springs, flywheels, compressed air containers, and other types of thermal or electrochemical storage devices. In addition, no devices specifically designed to store energy for the purpose of propelling the vehicle can be included in its drive train.

Project Presentation

The oral presentation provides an opportunity for the participating teams to discuss the design process and to highlight the special features of their vehicle. The presentation should include a description of the vehicle and a summary of the team's development process. Each team is allowed a minimum of three and a maximum of ten minutes for their presentation. Equal scoring weight is given to both content and delivery. As a result, it is important to allow adequate time for preparing and producing the presentation as well as practicing its delivery. A team of judges selected from the faculty and participating ASME members evaluates the presentations. Visual-aid equipment is provided for projection onto a large screen.

The presentation may be given by a single team member or by a group of team members. Regardless of how it is accomplished, the students are required to communicate their ideas effectively. There is also a set time limit for the presentation requiring the students to consider that too much technical detail can weigh down an otherwise good presentation. This is where a cross-functional team may prove beneficial. Team members from other disciplines such as business or journalism prove to be extremely helpful improving the presentation. This type of diverse team is precisely what the students are likely to face in their future work environments.

There are also penalties for teams that exceed the maximum presentation time. Teams, which run over the ten-minute maximum time limit, are assessed negative points against their score based on the following scale. For each 30 seconds or any part thereof over ten minutes the team receives one negative point up to a maximum of 4 negative points for a two minute overrun. The total penalty is then calculated by multiplying it by the number of judges, before it is added to the team's overall score. Presentations that exceed twelve minutes are automatically disqualified. In addition, presentations under the minimum three minutes are also automatically disqualified.

The winning team of the presentation event is determined by summation of raw scores from all judges plus the addition of any bonus points for supplemental items that were submitted at the time of registration minus any time penalties. Ties for first and second are settled by a blind ballot vote of the judging staff.

Vehicle Performance

The goal of this contest is to present an opportunity for students to demonstrate the capabilities of their human powered paper vehicles in a balanced competition free from serious accidents.

Once the timed vehicle run starts, no one other than the riders can have contact with the vehicle. This event is scored based on the course completion time, addition of bonuses, and subtraction of penalties. The team scoring the lowest net elapsed time to complete the course wins the event.

Any team, which has not completed the course within 10 minutes of their start, will be asked to stop and remove their vehicle from the course. All vehicles are allowed only a single attempt at completing the course. Exceptions to this rule and any resulting penalties are at the discretion of the course judging staff. Protests may be filed by opposing teams if a second attempt is allowed.

Riders are accessed a 10% time penalty for each instance that the rider physically touches the floor. An additional 10% time penalty is assessed for each time a pylon or a pullout cone comes in contact with the rider. A 10% time penalty will be assessed if the vehicle does not come to a complete stop in the pullout areas before the next rider makes contact with the vehicle. This penalty is assessed separately for each of the three rider transfers.

Safety

All riders must wear helmets that meet ANSI Standard Z90.4 (standard bicycle helmet) while:

- Warming up or orienting themselves on the event course;
- Riding in the event; and
- Riding any competing vehicle or other human-powered vehicle in close proximity to the event course.

All surfaces of the vehicle must be free from sharp edges and protrusions, both on the exterior surfaces and in the interior in the region of the rider.

Vehicle Competition

The race is held on a 200 meter indoor oval track. The overall course is 1-1/2 laps or 300 meters. Each of the three riders must complete one-third of the course or 100 meters.

From the starting position, the first rider must travel clockwise around the track and successfully navigate five obstacle pylons placed 15 feet apart. The rider must pass between each pair of pylons in a weave pattern. The rider then continues on and enters the first pullout where they must come to a complete stop before changing over to the second rider.

The second rider then leaves the first pullout and continues clockwise around the track. This rider must pass over the Ramp Bridge (which is 23 feet in overall length with a 10.6˚ incline to a flat surface and a similar return decline) and then proceed into the second pullout. They must come to a complete stop before changing over to the third rider.

The third and final rider must travel clockwise around the track and once again successfully navigate the five obstacle pylons that are placed 15 feet apart. The rider must pass between each pair of pylons in a weave pattern. The rider then continues on to the finish line to complete the course.

Competition Photos

The best way to illustrate the creativity and ingenuity displayed by the students is to present a few photos of their vehicles from past competitions. Additional photos and information from all previous competitions including the winners are available on the HPPV web site located at: http://www.technology.ewu.edu/hppv/main.htm



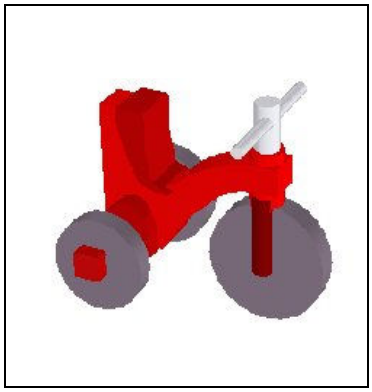
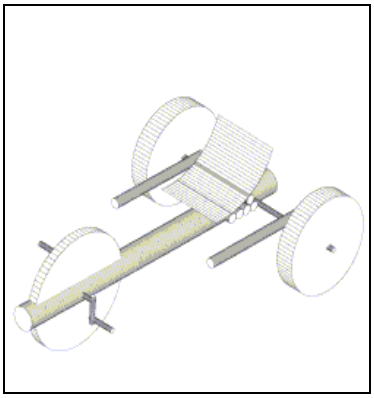
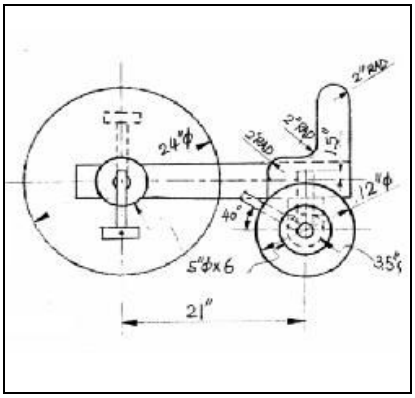


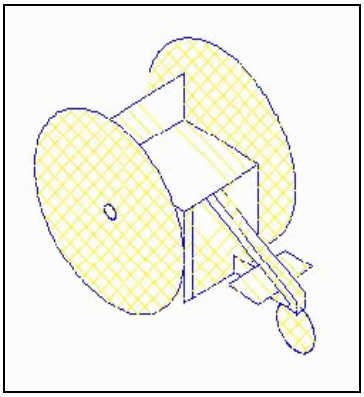
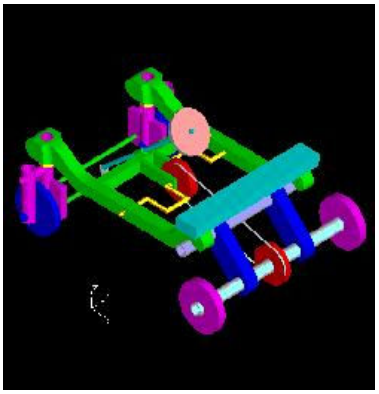




Vehicle Design

Several colleges and universities have incorporated the competition directly into their design and drafting courses. Some examples of the work produced by various teams that have competed over the years are presented below.

Lessons Learned

After eight years of competition numerous lessons have been learned from the HPPV competition. As a consequence, many of them have been directly incorporated into the competition. The result has been an improved and more competitive event with an expanding level of participation from colleges and universities.

A great deal of thought went into developing the rules, particularly those around the specific restrictions in vehicle design. The competition rules had to be clear and complete to ensure a fair contest. Design restrictions were required to keep students within the intent of the competition without stifling their creativity. At one point the rules were even revised to incorporate vehicle weight bonuses. The goal was to try to push students to more innovative and diverse designs. The unintended result was that many teams under-built their vehicles in an attempt to get the bonus points for a lower weight. As a result, many of these vehicles failed to finish the race. It was interesting to observe that many of the teams became so focused on the bonus points that

they lost track of the primary goal of constructing a vehicle that could complete the course. After two years the weight bonus system was scrapped and vehicle performance statistics are now improving.

The design of the track and the course rules also required careful consideration. Requiring three different individuals to operate the vehicle made it much more challenging than building to a single rider's specifications. The requirement to navigate through pylons created a specification for maneuverability. The inclusion of the Ramp Bridge meant that fast vehicles had to be built to withstand the additional strains of a sudden incline and decline while slower vehicles had to be able to withstand the increased demands on their drive mechanism. Even though the design of the course has never changed, it is noteworthy that virtually every team that has faced moderate mechanical failure during the race has attempted to nurse their vehicle along to complete the course. In some cases this has resulted in extreme tests for the rider's physical or mental endurance and clearly demonstrates the student's commitment to the success of their project.

In order to improve vehicle designs and assist new colleges and universities, a helpful hints page has been added to the official HPPV competition web site. Included are descriptions and pictures of what has worked in the past along with suggestions for a successful design including the proper use of materials. In addition, information is provided detailing where vehicles tend to have the most problems and failures. This information has become particularly useful for teams entering their first competition.

The ideal team consists of at least one returning competitor with new members, which will be returning for future competitions, added to fill out the team. This mix ensures that the experience from one year is passed on to the next. When an entire team from one year is returning, serious thought should be given to dividing the experienced team members into two teams. This allows for new team members to learn from the veterans. This approach to develop new teams encourages less experienced students (particularly freshman) to feel that they can contribute to the overall success of the team.

Perhaps the most important lesson learned deals with time. Designing, building, and testing the vehicle takes far more time and effort than most student teams initially consider. The top teams begin the process early and work continuously on their vehicle right up to the competition. The late starters rarely do well or even complete the course.

Research has shown that the earlier a student becomes involved in the department with other students, the greater the success of retention in the major. As a result, teams should be formed as early as possible to allow the team to have ample time for design, prototyping and testing. This fun and exciting competition has fostered a great deal of interest in engineering that has led to new students in the major as well as retention of existing students.

Conclusions, Reflections and the Future

The HPPV competition has grown into a very popular annual event. The contest is challenging enough to hold the student's interest without being too complicated and overwhelming. In

addition, the cost of the competition is minimal to encourage more colleges and universities along with their students to participate.

The contest introduces students to all of the typical product design steps and processes. Many times they discover that good designs on paper don't always work well when built. Faculty involvement is limited to being a coach and mentor. However, the encouragement and interest of the faculty is a key component and extremely important in sparking student interest and commitment. The design and fabrication of the vehicle is done entirely by the student's which leads to real ownership in the competition by the student team.

The students enjoy and benefit a great deal from the process. Even when a vehicle fails catastrophically in the race they all seem to laugh and have a sense of pride for just competing. This is a very valuable lesson to be learned in life. Everyone experiences setbacks, needs to learn from them, and then move forward. They don't consider themselves as failures because they didn't win. They all succeeded in team building and learning something new from the experience.

As the competition continues to grow, future consideration may include holding separate area and regional competitions. The top two or three teams from each of these events would then be invited to Eastern Washington University for the overall HPPV finals. This would further expand the competition while keeping costs low allowing additional colleges and universities to field teams and compete close to home.

From the very beginning, the faculty members from the competing colleges and universities have enjoyed working with and watching their student's compete. The sense of camaraderie and hope that develops is truly a wonder and joy to experience. Eastern Washington University plans to continue this tradition by hosting the competition for many years to come. New colleges and universities are strongly encouraged and invited to participate in this extremely rewarding event and build a closer bond with their students.

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Biographical Information

DONALD C. RICHTER obtained his B. Sc. in Aeronautical and Astronautical Engineering from the Ohio State University, M.S. and Ph.D. in Engineering from the University of Arkansas. He holds a Professional Engineer certification and worked as an Engineer and Engineering Manger in industry for 20 years before teaching. His interests include project management, robotics /automation and air pollution dispersion modeling.

WILLIAM R. LOENDORF obtained his B.Sc. in Engineering Science at the University of Wisconsin - Parkside, M.S. in Electrical Engineering at Colorado State University, and M.B.A. at the Lake Forest Graduate School of Management. He holds a Professional Engineer certification and was previously an Engineering Manager at Motorola. His interests include engineering management, real-time embedded systems, and digital signal processing.

KEITH TURPIN obtained his B.Sc. in Mechanical Engineering Technology at Eastern Washington University and M.S. in Computer Systems at City University. He has worked at The Boeing Company as a manufacturing engineer on the 747 airplane program, a computer systems specialist and a computing security specialist. His professional interests include information security for international engineering projects.