9668 | Innovating Mobility: A Student Competition in Wheel and Track Design

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A B S T R A C T

In this paper, we propose a new initiative for an ISTVS Wheel/Track Design Student Competition, aimed at engaging students in terramechanics and providing hands-on experience in off-road wheel/track design and testing. The competition will challenge student teams to design and fabricate a wheel or track system for a small unmanned ground vehicle (UGV), which will then undergo a series of tractive performance and mobility tests in selected soil types and conditions. By minimizing costs and focusing on practical, accessible design and testing methods, the competition ensures that students from various backgrounds and disciplines at any educational institution can participate. To support accessibility, our goal is to initially maintain a low barrier to entry by utilizing free software and affordable materials whenever possible. For example, teams can use freely available CAD software, 3D printing or other rapid prototyping techniques.

The competition details will vary from year to year. Initially, we propose a competition with two components: a laboratory-style terramechanics test rig with a single wheel soil test bin to test wheel/track design, and a small UGV similar to a radio-controlled (RC) car to test wheel/track design in different mobility/terrain tests. Performance tests may include measurement of drawbar pull, sinkage, slip, gross traction, and slope climbing characterization in alignment with ISTVS standards (He et al., 2020).

A single-wheeled terramechanics test rig will assess the wheel/track performance in controlled environments, supplemented by the small vehicle-based mobility tests under various soil conditions in the field. Each competition will include design presentations and performance tests evaluated using structured scoring criteria. The performance evaluation will be conducted using a test matrix that examines both structural integrity and performance. Through this competition, students will gain valuable experience, develop innovative solutions, and establish connections to ISTVS, fostering the next generation of terramechanics engineers.

Keywords
Terramechanics
Off-road mobility
Hands-on/Experiential Learning
ISTVS student competitions
Rapid Prototyping

1. Introduction

With the increasing number of graduates from engineering programs across the world, there is a need to augment traditional classroom theory with hands-on, or experiential learning. Experiential learning is defined as "a teaching philosophy in which educators purposely engage with learners in direct experience and focused reflection in order to increase knowledge, develop skills, clarify values, and develop people's capacity to contribute to their communities" (Tembrevilla et al., 2024). Terramechanics, a critical subfield of engineering, focuses on the interaction between vehicles and various types of terrain—making it highly relevant to applications involving wheeled or tracked systems.

To promote hands-on learning in this field, Mississippi State University, Virginia Tech, and University of Pretoria student chapters of the International Society for Terrain Vehicle Systems (ISTVS)—a professional network of researchers and engineers specializing in terramechanics—proposes a student competition designed to cultivate essential engineering skills. The goal is for interested universities/organizations to form an ISTVS student chapter, where members are then registered for the ISTVS Student Competition. This is to encourage interest in the field of terramechanics while increasing the number of members in ISTVS.

The competition will emphasize teamwork, engineering design, and technical communication while introducing participants to key concepts in characterizing off-road tractive performance for wheeled and tracked vehicles. For the first competition, each student team will be tasked with designing and prototyping a unique wheel or track system, culminating in the live testing and evaluation at the 56th Conference of the International Society of Terrain-Vehicle Systems scheduled in the last quarter of 2026 at the University of Pretoria, South Africa.

This paper outlines a proposal for the first of its kind ISTVS student competition: what is possible for the first competition in 2026, ideas for next competitions, and an invitation to discuss and receive feedback from interested external parties. In this paper the methodology of designing, testing, and evaluation of the wheel or track system is outlined, with flexibility to adjust requirements based on feedback. Requirements are outlined for the student teams to document their design process and include the design report as part of the competition, which can be judged through a review process as well as a design presentation hosted at the ISTVS conferences. In addition to the design requirements expected from the student teams, information is presented for the proposed test platforms that can be used to assess the performance of the student designs.

Two test platforms are proposed, consisting of a laboratory-style single-wheel soil bin test platform to ensure repeatable experiments as well as a small UGV or similar RC-like vehicle to assess dynamic maneuvers and tests. The laboratory-style single-wheel test apparatus will be used to test the wheel performance in a controlled and repeatable manner. The soil properties will be established first, followed by measurements of drawbar pull, gross traction, and sinkage of the wheel at varying forward and angular speeds. The new wheels will then be installed on a radio-controlled vehicle to test basic mobility metrics such as acceleration, deceleration, time to cover a specific distance, or a distance

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travelled in a specified time, aiming to correlate single-wheel performance with overall vehicle capabilities. Finally, a proposal is made for scoring the various aspects of the student competition, including the design document, presentation, and experimental results, to crown a winner of the student competition.

2. Methodology

Along with the call for papers, universities will receive notification of the upcoming ISTVS Student Competition for the 2026 ISTVS conference, including a competition rulebook, deadlines, and schedules. This will be advertised by various means, including digital flyers on social media and mass email distribution. On the flyer or email will be a link to an online form platform where interested students can sign up for an interest meeting to get more information from competition organizers. During this information session, interested groups can ask any questions they may have regarding the competition. At the end of this information session, a sign-up link will be sent out to the interested parties. Teams can then register through the link, where they will be prompted to input their university/organization name and team member information before the selected registration deadline. At the conclusion of the registration period, those teams will receive further instructions via email.

2.1. Competition Organization

The student team captain will be the primary point of contact for all organization correspondence with support and involvement from the faculty advisors. They will both be required to be listed at registration. Upon confirmation of registration once the period of registration closes, the advisor and team captain will receive an email with details such as how to get started as well as receiving notification that they will be receiving a competition kit shortly with the proper materials to get their team started. Teams must design and deliver a 3D printable file in a prescribed format (e.g., .stl) containing their proposed wheel/track design to be submitted to the ISTVS competition organizers for rapid prototyping and testing.

The schedule for the competition will be provided by the student competition executive board in conjunction with that year's hosting university. The competition organizers will then print their file and test it during the conference time frame with the proposed testing apparatus discussed in sections 3.2 and 3.3. Judge selection for the ISTVS Student Competition will be made by a committee formed by the ISTVS board of directors. These judges will be chosen based on factors such as availability to help with the competition organization and judging, as well as having relevant topic area expertise. Competition judges will be responsible for helping facilitate the proceedings of the ISTVS Student Competition at the competition site. These responsibilities will include scoring students based on the grading rubric, providing feedback to students, as well as coordinating between competition organizers and competing student teams. The duties of the judges will change from year to year, depending on the metrics being tested. The debut of the ISTVS Student Competition will be held in South Africa at the University of Pretoria in 2026. A livestream will be set up for those universities unable to travel to the competition site. The competition will be held at the ISTVS conference venue.

2.2. Design Methodology

Students will design a wheel or tread track based on the small ground-vehicle platform provided as a basis for that competition year, such as an RC car. Designs will be tested with a single-wheeled testing rig, like the one shown below in Fig. 1. Each team will design their wheel or track based on the criteria being tested in a specific competition, such as maximizing drawbar pull, minimizing rolling resistance, improving traction, and provide their design in a well-established prescribed format, which can be created using software such as SolidWorks or Blender. Design parameters such as size, geometry, and orientation of parts will need to follow the specifications and reflect the parameters being tested for that competition year. These specifications may vary from year to year, depending on what hardware is chosen and other limitations.

Fig. 1. Single-wheel test platform at TMVS lab, Virginia Tech

Wheel and/or track designs submitted by students will be manufactured and prototyped with inexpensive methods such as 3D printing, as seen in Fig. 2. and Fig. 3. The type of filament or other material used to prototype each team's design will vary depending on what resources are available at the organizing university but will be the same for each competing team. Faculty advisors for the student teams are allowed to give general advice but may not design the wheel or tread pattern for the students.

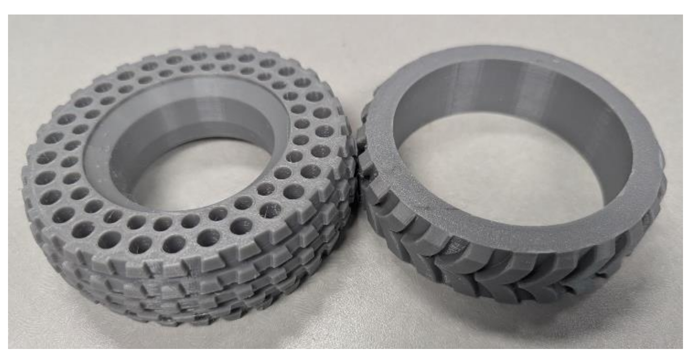

Fig. 2: Examples of 3D printed wheel design, CAVS MSU

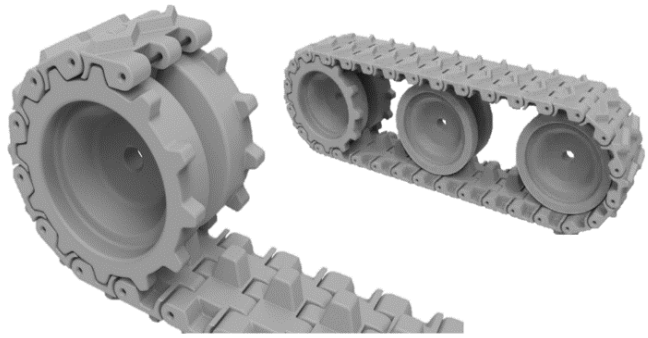

Fig. 3: Examples of 3D printed track design, CAVS MSU

3. Competition Test Cases

The competition can consist of different events, with each year having a different focus depending on the resources available and the local conference team. A detailed rulebook will be sent out to the universities every year to discuss the specifics of that event.

We propose below the different competitions and test metrics that can take place every year to engage students across universities. First, a technical design presentation is given by the teams to introduce to the audience the design methodology, leveraged technologies, modeling and simulation efforts that influenced the design decisions. After this, the design is tested using different benchmarks. We propose two methods to evaluate the design: the indoor controlled testing and the outdoor testing, depending on the resources available to the local conference team for evaluating the different teams' designs. Sensors, timers, and/or cameras will be used to measure the relevant performance parameters to provide an absolute scale on which the teams will be ranked. This section explores these ideas, proposing the different tests that can be performed, encouraging different test matrices for the dynamic evaluation and different goals for each year.

3.1. Design Presentation

The design presentation serves as the first opportunity for students to showcase their evaluation techniques and approach to the problem statement. Teams are expected to present various design alternatives, along with their evaluation criteria and the rationale behind selecting the final design . Suggested methodologies for performance prediction include but are not limited to: (a) Empirical models (e.g., tire numeric), (b) Analytical modeling (e.g., Bekker-Wong model), (c) High-fidelity simulations (e.g., FEM models), and (d) Experimental testing. A peer-review strategy is proposed for evaluating the presentations to ensure constructive feedback and knowledge exchange. Additionally, teams are encouraged to submit conference papers based on their findings, contributing to the broader research community, like the referenced article (Sinha & Gupta, 2023). Engaging in such scholarly discussions will help refine their methodologies and promote innovation in the field.

3.2. Controlled Testing

Following the design presentation and based on the competition rules and constraints from each year's conference organizers, a series of controlled, laboratory-style tests will be conducted on the submitted wheel or track systems. These test conditions will be included in the rules and will be shared with student teams well in advance to inform their design process. To promote innovation and avoid incremental design improvements, the competition parameters will vary annually. Changes may include geometry constraints, test procedures, or evaluation metrics. Accordingly, the test platform must be versatile enough to accommodate different configurations while remaining simple to install, operate, and transport between conferences. A modular design will support ease of assembly and adaptability. Soil properties and wheel performance will be measured in line with ISTVS standards (He et al., 2020). For soil characterization, unless the soil properties were already established, pressure–sinkage and/or shear strength measurements (Okello, 1991) will be performed. For wheel performance, established terramechanics performance metrics can include drawbar pull, gross traction, rolling resistance, sinkage, and their dependence on slip. The overall vehicle performance can be characterized by gradeability, startability, and obstacle traversal.

Student teams attending the conference may have the opportunity to directly interact with the controlled testing apparatus. For teams unable to attend in person, competition organizers will conduct testing on their behalf.

3.3. Single Wheel Test Platform

To assess these metrics, a standardized test setup is proposed. A scaled version of the single wheel test-rig at Virginia Tech, illustrated in Fig. 1, can be utilized to evaluate the performance of the 3D printed wheels. At its core is a small soil bin (approx. *2.0* m long, *1.0* m wide, *0.6* m deep), constructed from low-cost materials by each year's organizers. Soil selection is flexible, ideally reflecting local conditions to add variability. Careful soil preparation is proposed in between test runs to provide fair and similar initial conditions for each team. The conference organizers can measure and supply soil properties well in advance to the teams. The test platform may be fixed to the soil bin or mounted on rails or with a rack and pinion setup to traverse its length. In both cases, relative motion between the wheel/track and soil is controlled using electric motors, possibly with gearboxes and belt/pulley systems. Independent control of wheel and carriage speed enables precise slip ratio testing. Vertical load can be varied using standard weights mounted on the carriage. The total mass will be provided to teams in advance, eliminating the need for onboard load measurement. The soil bin may also be inclined or fitted with mechanisms to vary slope between tests. Careful soil preparation is critical for consistency. Obstacle traversal can be introduced using rigid or removable fixtures placed in the soil bin, defined by organizers or as part of the challenge. This modular, adaptable setup enables rigorous evaluation across a range of metrics. By varying the test focus annually, the competition can remain engaging and technically meaningful. It also offers students valuable exposure to experimental methods in terramechanics within a fun and collaborative environment.

3.4. Controlled Testing Measurement Systems

Accurate sensing and control are essential for repeatable results. A brief list of sensors and measurements required to accurately assess team designs is included. To measure the wheel or track states, encoders can be installed on the electric motors to measure motor revolutions and calculate speeds. Similar encoders can be installed on the carriage drive system to measure and infer the carriage speeds to determine the wheel slip ratios. The electric motor drive torques can be inferred via current sensors and forces measured directly using load cells between the drivetrain and frame. Laser displacement sensors can measure rut depth and sinkage, placed ahead of, next to, and behind the wheel.

3.5. Test Platform Proposed for the Inaugural ISTVS Student Competition

From this extensive list of configurations, test cases, and measurement systems, the following selection is proposed for the first competition, with flexibility for change based on recommendations and discussion from the wider ISTVS community.

- The initial design will make use of a single wheel design.
- A simple, horizontally flat soil bin with a carriage system driven with an electric motor on a rack and pinion to propel the carriage in a controlled manner along the soil bin.
- The wheel subassembly, with its own driving motor and gearbox, is attached to the carriage to control relative wheel speed.
- The wheel subassembly is mounted with linear rails to enable free movement in the vertical direction. Provision is made here to add pre-defined weights to vary the vertical load.
- Load cells are installed horizontally in between the linear rails and the carriage system to enable measurement of drawbar pull forces.
- All electric motors are instrumented with encoders, possibly torque/current sensors, and appropriate drivers to enable angular speed and torque/current measurements and control.

With this configuration, the drawbar pull, longitudinal slip ratio, power requirements, and efficiency can be measured, enabling an extensive list of testing criteria to evaluate the performance of each team's wheel design in a controlled manner. This method of evaluation, however, also has drawbacks such as limitations on the longitudinal velocity of the wheel. The test platform provides information on the performance of a single wheel; however, the performance of a wheeled vehicle cannot be estimated effectively using the single wheel test results. The test platform may also present a logistics challenge as it needs to be disassembled and transported to the next conference venue each year. Also, the teams whose facilities have the capability to run such tests may host certain elements of each year's competition until more teams can acquire the necessary equipment. As the competition evolves, the platform can be updated to accommodate additional evaluation parameters.

3.6. Tests On Small Unmanned Ground Vehicles

The competition may also test the manufactured wheel on a small UGV (e.g., RC car) to assess its behavior in dynamic maneuvers. The specific test setup will be determined based on the conference location and available resources for that year. Teams will be provided with key details, including: (a) UGV specifications (weight, dimensions, number of wheels, drivetrain type), (b) soil characteristics (e.g., cone index, engineering properties, moisture content), and (c) maneuver conditions (target speed, maximum steering angle, torque/engine power limits). Below in Fig. 4 is an example of a small UGV platform at the Center for Advanced Vehicular Systems (CAVS) that might be used as a test vehicle by competition organizers.

Fig. 4: An example small UGV or 'RC car', CAVS MSU

Given a specified soil type, the following maneuvers are proposed: (a) acceleration/braking test, (b) cornering tests, (c) hill climb test, and (d) wet soil traction test. To ensure repeatability, tests will be performed under controlled environmental conditions with consistent soil preparation. Soil properties such as moisture content, density, and strength will be measured to verify uniformity. The vehicle's onboard sensors will log real-time data, including wheel speed and lateral and longitudinal acceleration, providing objective performance metrics. Additionally, post-test analysis, including visual inspection of soil displacement and rut formation, will offer further qualitative insights into wheel effectiveness on different terrains. This method of evaluation will provide better insight into how the designed wheel performs on a vehicle. However, this method would limit the dimensions of the wheels to the size of the RC car. Also, the selected sensors should be feasible to instrument the vehicle.

3.7. Measurement Systems for Small Unmanned Vehicles

For tests on small UGVs or RC cars, the sensor suite should be accurate and reliable, as vehicle tests will be subject to more disturbances. Establish a well-characterized sand/soil pit—thoroughly measured, compacted, and calibrated—to ensure uniform driving conditions. Onboard accelerometers are sufficient for capturing vehicle acceleration, while slope climb and wet-traction performance can be assessed by recording the elapsed time for each run.

4. Assessment of Design and Scoring

Each team's design reports will be assessed by a panel of experts, ideally from the ISTVS community. It should reflect sound engineering judgement and a clear understanding of the design problem. Each panel member will independently score the report to ensure consistency and reduce bias. Ideally, this evaluation should take place before the conference so that the overall competition winner can be announced during the event.

Design presentations will be judged at the conference by a panel including ISTVS members, local organizers, and invited experts. Presentations should clearly communicate the design approach, justify key decisions, and demonstrate the team's ability to respond to questions. While in-person presentations are preferred, provisions can be made for remote participation via recordings if needed.

Scoring for the controlled testing will rely on objective performance metrics based on the competition's specific constraints and rules. These parameters will be measured using the test platforms and used to assess each design's performance.

In addition to expert reviews, peer assessment between teams is encouraged to promote collaboration, knowledge exchange, and networking. A portion of the final score may reflect these peer evaluations, contributing to a student team choice award.

Winners may be announced in each segment—design report, presentation, testing, and peer award—with an overall winner determined through a weighted combination of all segments. This assessment and scoring of the event will be done on-site after the competition by a panel of judges assembled by the committee formed by the ISTVS board of directors. While this favors teams participating in all areas, those entering select segments still have the chance for recognition. There will be 1st, 2nd, and 3rd place winners, with a special category for the Student's Choice Design Award winner. Special recognition will be given to winners of the student competition in the form of unique ISTVS-themed trophies for that competition year, certificates, useful tools or equipment, and eventually monetary prizes as funding for the student competition grows. This funding will come from external entities such as industry experts in the field of terramechanics who are interested in promoting greater student interest in the field.

The assessment and scoring framework is still under development and open to feedback. Organizers plan to draw on existing models from similar competitions, such as Formula SAE (SAE International, 2024a), Baja SAE (SAE International, 2025) and Mini Baja SAE (SAE International, 2024b), to help shape the final rulebook that will be shared with student teams. The current approach serves as an initial foundation and will be refined over time through input from participants, organizers, and the broader ISTVS community.

5. Conclusions and Future Work

This paper suggests the first of its kind ISTVS student competition series. It outlines the goal of the first competition, which is the design of a wheel or track element for an off-road vehicle. Requirements are listed for the student teams: 1) document and provide arguments for your design process, and 2) include the design report as part of a conference poster submission, which will be judged through a review process as well as a presentation hosted at the ISTVS conferences. Two test platforms for the design are proposed: 1) an indoor single-wheel test rig with soil bin, and 2) a radio-controlled (RC) car or similar small, unmanned ground vehicle (UGV) with the newly designed tractive element installed. The single-wheel test rig will measure the drawbar pull, gross traction, rolling resistance, and sinkage of the wheel at various slips in a controlled environment. A small UGV will be used to correlate the single-wheel test results with the full vehicle performance, such as acceleration, deceleration, slope climb, and time to cover a specific distance.

Multiple aspects of the student design, including the design document, presentation, and experimental results, will be used to score the competing teams and to crown a winner of the student competition. The detailed rules and schedule for the 2026 competition will be established and distributed after the 2025 ISTVS conference by the competition-hosting entity, which is the ISTVS student chapter of the University of Pretoria. The final testing and scoring of the teams will be performed at the 2026 ISTVS conference.

We actively welcome the feedback and involvement from ISTVS members, academic institutions, and industry partners that are interested in contributing to or hosting the competition. This collaborative approach will ensure the competition reflects the shared goals and insights of the broader terramechanics community.

For future work, we aim to increase participation, seek and incorporate feedback, and ask for ideas for the future competitions from the conference attendees and later from the general ISTVS community. Any ideas to expand or incorporate more areas of interest in the future, like autonomy for the UGVs, are welcome. Soliciting sponsorship from external groups will be key to growing the program in coming years. This sponsorship will only further elevate the prestige of the event and help offset costs for student teams interested in participating. These costs can include travel costs associated with travelling to the ISTVS conference as well as any design-related costs such as filament for 3D printers. Broader engagement will be key to refining the concept and ensuring the long-term success and relevance of the competition.

6. Acknowledgements

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7. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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