Society of Petroleum Engineers
Drilling Systems Automation
Technical Section (DSATS)
International University Competition
2023-2024

Drillbotics® Guidelines

Group A

Revised 11 October 2023

Version	Date	Section	Description
2024.01	11 October 2023	All	initial release

1. Introduction

This year marks the tenth competition for the title of Drillbotics® champion and a chance for students to learn about the drilling process from industry experts and for winning team(s) to travel and present a paper at the next SPE/IADC Drilling Conference and at an event organized by DSATS. The past years involved undergraduates, masters and doctoral students from a variety of disciplines who built innovative drilling machines and downhole tools while developing a deeper understanding of automating the drilling process. Recently, this was extended to include teams who created models of the rig, the drilling process, and various downhole interactions. Teams freely shared lessons learned, which more rapidly advances the science of drilling automation. Everyone involved claims to have had a lot of fun while learning things that are not in the textbooks or published papers. Students also participated in related events at conferences, workshop meetings and networking with industry leaders in drilling automation. This year's contest promises to be just as challenging and hopefully as much fun. For more information, see https://drillbotics.com/

> **New for 2024**
>
> Continue with two groups
> A – Virtual
> B – Physical
> Separate guidelines for each group to reduce confusion
>
> Group A:
> - Create model (or option to use publicly available models) to simulate a virtual rig, or
> - Use their rig model to interface with a well control model provided by Norce using their OpenLab simulator.
>
> Group B:
> - Build and operate a physical rig to drill a 2D directional well or an optional 3D well.
>
> For A & B: Additional credit for teams that develop a D-WIS compatible API for data interoperability.
>
> Okay for two schools to join together for their entry.

This year's Group A competition again allows teams two options. They may compete like previous years, virtually drilling a directional well. Optionally, they may choose to focus on virtually detecting and controlling a well control event (e.g., kick). Group B will drill a 2-dimensional directional well under similar guidelines to last year, but may opt to drill a 3-dimensional well.

New Group A teams are highly encouraged to use the OpenLab Drilling Simulator (https://openlab.app/) and focus on designing the controls system. The D-WIS interface and connectivity will be used to send set-points to the simulator and receive surface and downhole sensor data. Webinar training on how to use the D-WIS interface and the simulator will be provided in October. Group B teams could use the simulator to validate and verify the interoperability of their API.

Previously, teams reviewing the contest rules had to jump between the main body of the guidelines to various appendices depending on which group they chose. This year we have created separate guidelines for Groups A and B. The general information items that are common to both groups are identical. Rules specific to each group are listed in an appendix. Teams must also monitor the website (www.Drillbotics.com) to check any Frequently Asked Questions (FAQs) since they become part of these guidelines.

How did the competition first come about? The origins began in 2008 when several SPE members established the Drilling Systems Automation Technical Section (DSATS) to help accelerate the uptake of automation in the drilling industry. DSATS' goal was to link the surface machines with downhole machines, tools, and measurements in drilling systems automation (DSA), thereby improving drilling safety and efficiency. Later, at an SPE Forum in Paris, the idea of a student competition began to take shape; a DSATS sub-committee was formed to develop the competition format and guidelines further. Several universities were polled to find out the ability of academic institutions to create and manage multi-disciplinary teams. The Drillbotics committee began small in 2014-2015 to see if the format could succeed. With fine tuning, we continue along those lines as we start the 2024 process.

Competition Overview:

Group A

- Option 1: The teams will design a control system that will virtually control their full-scale drilling system model to test and demonstrate their automated system's capability to drill a directional well. The teams should incorporate virtual downhole and surface sensors in their automation and controls scheme. The well path will be defined by three targets provided by the Drillbotics Committee immediately before the final Phase II test. Teams can drill a 2D or an optional 3D trajectory.
- Option 2: Teams may use the D-WIS interface standard to connect to an OpenLab simulator offered by Norce to detect and control an influx (kick).

Group B

- The challenge requires teams to develop a small-scale drilling rig and control system to autonomously drill a directional well following a given trajectory.
- Downhole sensors are mandatory, and their data must be included in the control algorithms.
- The well path will be defined by three targets provided by the Drillbotics Committee immediately before the final Phase II test. Teams can drill a 2D or an optional 3D trajectory.

Phase I

- Both groups must submit a Phase I Design Report not later than 31 December.
- A Phase I Design Video is optional, due not later than 15 January.
- Judges will review the reports and select finalists to be announced in early February.

Phase II

- Teams will submit a pre-recorded team presentation approximately one week before the Phase II test. Judges will review the presentation and prepare a list of questions that will be asked of each team prior to the physical test.

Tests

- Group A and B Phase II tests will be held on separate dates, to be advised in April. If possible, we will hold face-to-face tests in Germany and the USA, with an option for a virtual meeting on the same dates.

The DSATS technical section believes that this challenge benefits students in several ways. Petroleum, mechanical, electrical, and control engineers gain hands-on experience in each person's area of expertise that forms a solid foundation for post-graduate careers. Those involved with system modeling gain insight into how models can gain sufficient fidelity to be applied to industry specific problems. They also learn where poor models or poor data can lead to incorrect outcomes. Students also develop experience working in multi-disciplinary teams, which is essential in today's technology-driven industries. Winning teams must possess a variety of skills. The mechanical and electrical engineers need to build a stable, reliable, and functional drilling rig. Control engineers need to architect a system for real-time control, including a selection of sensors, data handling, and fast-acting control algorithms. The petroleum engineers need an understanding of drilling dysfunctions and mitigation techniques. Modeling engineers must understand all of these basics and how to organize numerous modules into a complex model. Everyone must work collectively to establish functional system requirements, often fully understood by each team member to accurately portray the drilling issues and create an integrated package working seamlessly together.

The oil and gas industry today seeks lower costs and reduced risk through efficiency and innovation. Many student competitors may discover innovative tools and control processes that will assist drillers in speeding the time to drill and complete a well. This includes more than a faster ROP, such as problem avoidance for dysfunctions like excessive vibrations, stuck pipe, and wellbore stability issues. Student teams built new downhole tools using 3D printing techniques of designs that would be difficult, if not impossible to machine. They used creative hoisting and lowering systems. Teams modeled drilling performance in particular formations and adjusted the drilling parameters accordingly for changing downhole conditions. While they have a lot to learn about our business, we have a lot to learn about their fresh approach to today's problems. Good Luck!

The Drillbotics® Committee

Contents

2. *Objectives for the 2022 Competition*

2.1. During the school year, beginning in the fall of 2023, a team of students will organize themselves to solve a drilling-related problem outlined in Appendix A below. The team should preferably be a multi-disciplinary team that will bring unique skills to the group to allow them to design and construct hardware, software and models to demonstrate that they understand the underlying physics, the drilling issues and the usual means to mitigate the issues. We cannot stress enough the need to involve students with different technical training and backgrounds. They will need to develop skills to understand drilling dysfunctions and mitigation strategies, but they must also have the mechanical engineering and controls capabilities to model, design the rig/drilling package and develop the controls system. Even when the project involves only software, an understanding of the physical limits of a rig's machinery and tubulars is critical. In past years, some entrants have not adequately considered the control network and algorithms needed for autonomous drilling. They have often misunderstood the need for calibrated sensors and fast, accurate data handling. Some teams did not consider measurement errors. Teams from both Group A and B ignored uncertainty principles. All of this and more is needed to build and operate a complete automated drilling system. We encourage all teams to start out with a simple concept done well, and then build on it from year to year adding complexity when warranted. Planning for this evolution will make it easier on future team members.

2.2. The students should produce novel ideas leading to new drilling models, improved drilling machines and sensors, and the ability to integrate the data, models and machines that will hopefully create new, more efficient ways to drill wells in the future. Any such innovation will belong to the students and their university in accordance with the university's written policies. DSATS and SPE waive any claims to students' intellectual property.

2.3. The students, working as a multi-disciplinary team, will gain hands-on experience that will be directly applicable to a career in the upstream drilling industry.

3. *Background*

3.1. What is DSATS?

DSATS is a technical section of the Society of Petroleum Engineers (SPE) organized to promote the adoption of automation techniques using surface and downhole machines and instrumentation to improve the safety and efficiency of the drilling process. More information is available about DSATS at the DSATS homepage (https://www.spe-dsats.org/) .

3.2. Why an international competition?

DSATS and the other technical sections, as part of the SPE, are a group of volunteers from many nations, connected by their belief that drilling automation will have a long-term, positive influence on the drilling industry. This diversity helped to shape the direction of the organization. The group feels that the industry needs to attract young professionals from all cultures and disciplines to advance drilling practices in all areas of the world. The winners of the competition will receive a grant for economy class transportation and accommodations to attend the next SPE/IADC Drilling Conference and will present an SPE paper that will be added to the SPE archives of One Petro[1]. Note that this year, the Drillbotics Committee will submit both Group A and Group B winning abstracts to the conference program committee. They will choose which of the two abstracts best fit their program. The Drillbotics committee will help the winning team from the other Group receive recognition of their achievement and have the opportunity via a different conference[2] to publish an SPE paper that will be added to the SPE archives of One Petro. DSATS believes recognition at one of the industry's leading technical conferences will demonstrate to industry leaders the extent of research and understanding the student teams have gained during the contest. Also, the practical experience with drilling automation systems increases the students' visibility to the companies that are leading automation activities.

3.3. Why include a safety case

Safety of personnel, equipment and the environment are always critical for any drilling operation. The industry begins any project or operation with safety in mind, and a safety case is a proven method of identifying and mitigating risks. This is no different on a small scale or for a virual operation. Safety goes far beyond personal protective equipment. Where can someone be hurt – in a lab with heavy rock samples and rotating machinery? Electrocution? High pressure leaks? Traveling to and from locations? Judges want to see how teams plan ahead in their first few meetings to identify threats and develop processes or devices to reduce the risk and severity of any incidents.

3.4. Why include Human Factors?

Any complex engineered system that is wholly reliant upon human operators to achieve its goal is likely to experience issues. Humans are inconsistent when performing monitoring tasks, they tend to not make wholly rational decisions, are impacted by external factors and are prone to error. As technology advances and complexity increases (such as the control regimes proposed in remote drilling operations for example) such issues become more prevalent. However, many of the issues associated with such complexity can be countered by reallocating certain tasks to automation. Maintaining appropriate levels of automation and ensuring that your 'projected' drilling operator remains 'in the loop' through good interface design will be one of the key challenges you will face in the Drillbotics competition. It is imperative that teams show how they implemented human factors in their processes and interfaces, both in the creation of their rig or model and how the operators/judges will use their designs.

Students working with automated systems should learn about the risks and proper strategies to allow humans and machines to work together safely and efficiently. Reference documents are listed in Appendix B. Requirements for human factors provisions are shown in Appendix A.

[1] Publication is subject to the SPE program committee's acceptance of the abstract/paper. If the abstract is not accepted, DSATS will solicit other SPE events to try to get the paper into OnePetro. Travel authorization will depend on any international or local travel restrictions in place at the time of certain events.

[2] DSATS will submit an abstract to SPE, and if need be, to other organizations, in an effort to help teams publish the results of their work. The acceptance of any abstract depends solely on the program committees of such venues.

3.5. Items posted on the website are part of these Guidelines

The Drillbotics website at www.Drillbotics.com includes official updates to the competition guidelines and schedule, as well as FAQs, photos, and previous entrants' submittals and reports and numerous reference documents. **Any updates to the guidelines posted on the Drillbotics website via FAQs or blog entries from the Committee are considered to be an official revision to these Guidelines.**

3.6. Questions should be directed to the competition email at competition@drillbotics.com. Teams must provide the reference number of the section of the guideless when you ask questions. Questions and answers will be incorporated into the FAQs periodically.

4. *General Competition Guidelines*

4.1. Entrants to Group A challenge have the option to sign up to do a well control challenge. They will need to use OpenLab Drilling simulator (https://openlab.app/) with the D-WIS interface.

4.2. Teams also have the option to work on a 2D or optional 3D steering challenge. They will develop a drilling system model that represents a full-scale system and corresponding control scheme to virtually drill a directional well to a given trajectory as efficiently as possible within constraints of safety and economics.

4.3. The Group A challenge does not involve building a rig or drilling system. The teams will design automation and control modules to develop a virtual drilling system (i.e., computer models) to test and demonstrate the controls. Teams that develop modules that can updated in future years find that their code is stronger than a complete re-write.

4.4. The Group B challenge requires the design, construction, and operation of a physical mini-rig to physically drill a directional well to a given trajectory as efficiently as possible within constraints of safety and economics. Teams may work on a 2D or optional 3D steering challenge. The guidelines for Group B are published separately.

4.5. The contest covers only the drilling of one hole section. There is no need to run casing. There is no need for automated pipe handling at the surface. There is no logging or cementing. This is just a drilling problem. However, teams should consider sampling and surveying and dealing with uncertainty.

4.6. Judges want to see evidence that teams know about drilling and modeling aspects of well construction. Because teams will either build or model a physical rig and downhole conditions, they must specify the assumptions made about their project. Allowing judges to understand "why" you made certain choices affecting the evaluation of your project.

4.7. While the teams will have to meet minimum competition requirements, any exceptional contributions "above and beyond" the main theme will be rewarded with additional points to encourage creativity and innovation.

4.8. Teams are free to choose the hardware and software most suited to their design except where explicitly specified. Teams are free to choose any software language. Judges would like to see an explanation of the reason certain hardware or software was selected.

4.9. Teams are encouraged to review the design reports, presentations, and test recordings available on the website, since these include designs that worked or didn't work and students thoughts about their earlier choices.

5. Team Members

5.1. DSATS envisions that the students would be at least at the senior undergraduate or Masters level, well versed in the disciplines needed for such a project. The core team shall consist of at least three (3) team members and no more than five (5). Contributions from other team members is allowed, and all contributors should be recognized in the Phase I Design Report. The travel grant for the winning team will be limited to five (5) team members and one (1) supervisor due to budget constraints.

5.2. Any team that loses team members during the project can recruit a replacement. Note any changes to the team membership or the faculty advisor in the monthly reports. Include the email address of the new member(s). At least one member of the core team must be a Petroleum Engineering candidate with sufficient coursework completed to understand the physics relating to the drilling problems and the normal industry practices used to mitigate the problem. For universities that do not have a petroleum engineering program, two schools may join efforts to compete as a single entity (see 5.6)

5.3. Students with a background in mining, applied mathematics, mechanical and electrical engineering, as well as controls, mechatronics and automation or software development, are the most likely candidates, but students with any applicable background is encouraged.

5.4. A multi-disciplinary team simulates the working environment in the drilling industry today, as most products and services are produced with the cooperation of technical personnel from differing backgrounds and cultures.

5.5. A university may enter more than one team in a group and may enter teams in one or both groups.

5.6. A collaboration between not more than two universities is allowed, especially where one school may not offer a curriculum in a specific technical area needed to successfully conduct the project. The resulting team may only submit one Phase I design report. Also, the travel grant will still be limited to five (5) students and one (1) supervisor. Note: Any differences with intellectual property ownership between the two schools must be settled by the teams and shall not involve DSATS.

5.7. Students shall register their team not later than 15 October using the registration form on the Drillbotics website https://drillbotics.com/guidelines/. Please indicate the challenge (Well Control or 2D or 3D Steering) that the team will be participating in.

6. Safety

6.1. The team's safety plan should consider all foreseeable hazards and methods to mitigate them. Personal protective equipment is part of a safety plan but is far from sufficient. Teams must consider risks due to handling the rock, rotating machinery, electrical shock and others. What health considerations are in place? How the team communicates with each other before and during operations is also important. Judges will grade each team on its comprehensive safety plan. This applies to both Group A and Group B.

6.2. Because most of the Group B rigs have equipment spinning at high RPMs, some form of protective cover <u>must</u> be included in the team's rig design. A broken coupling, a loose screw or similar item becomes a projectile that can lead to serious injury to the team members, judges or visitors. Judges may decide to deny a team from competing if their design is unsafe. Similarly, Group A teams may be excluded if they have not met proper health and safety considerations.

6.3. The following links are a good starting point, but is by no means a comprehensive list of links:

6.3.1. OSHA Pocket Guide, Worker Safety Series: https://www.osha.gov/Publications/OSHA3252/3252.html

6.3.2. OSHA Checklist for General Industry: http://www.scosha.llronline.com/pdfs/genind.pdf

7. Expenditures

7.1. Teams selected to advance to the second phase must limit the cost of the physical or virtual rig and materials to US$ 10,000 per year or its equivalent in other currencies. Students may use previous work and make changes within the US$10,000 annual limit. The cost of transporting the rig to any local test sites is excluded. Student and supervisor travel is excluded. The students shall find a source of funding and report the source in the Phase I proposal. All funding and procurement should comply with university policy. These funds are intended to cover the majority of expenses for hardware, software and labor to construct and operate the team's equipment. Teams will not be reimbursed for travel to any local competitions. DSATS shall not be liable for any expenditure other than DSATS provided material and specified travel expenses.

7.2. DSATS will assist, when possible, to obtain free PLCs or similar control devices and software tools from suppliers affiliated with the DSATS organization. Such "in-kind" donations shall not be included in the team's project costs.

7.3. Students and universities may use other "in-kind" contributions which will not be included in the team's project costs. Such contributions may include modeling software, laboratory equipment and supplies, and similar paraphernalia usually associated with university laboratory projects.

7.4. Any team spending more than US$ 10,000, or its equivalent in other currencies, may be penalized for running over budget.

7.5. DSATS reserves the right to audit the team's and university's expenditures on this project.

7.6. Any devices built for the project will become the property of the university and can be used in future research and competitions. Any maintenance or operating costs incurred after the competition will not be paid by DSATS.

8. Other Considerations

8.1. University coursework and credit: Each university will decide whether or not this project qualifies as a credit(s) towards any degree program.

8.2. The design concepts shall be developed by the student team under the supervision of the faculty. Faculty and lab assistants should review the designs to ensure student safety.

8.3. Construction of any equipment shall be supervised by the student team but may use skilled labor such as welders and lab technicians. The use of outside assistance shall be discussed in the reports and the final paper. DSATS encourages the students to gain hands-on experience with the construction of the rig since this experience will be helpful to the career of individuals in the drilling industry.

8.4. Teams building a virtual rig may create new models or improve models from other teams at the same university or elsewhere. Be aware of open source models from groups such as the Open Source Drilling Community (https://opensourcedrilling.org/). Teams must cite the original work done by others. Teams are also encouraged to share their models with the OSDC.

9. Project Timeline

Phase I - Design:	Fall 2023
Submit monthly reports	On or before the final day of each month starting in October
Submit final design to DSATS	31 Dec 2023, midnight UTC
Submit an abstract to DSATS*	31 Dec 2023, midnight UTC
Finalists to advance to Phase II	Announced in mid-February 2024

*DSATS will submit an abstract to the SPE that will include excerpts from the student abstracts by the conference paper-submittal deadline, typically in mid-summer, for consideration of a paper by the conference program committee.

Phase II	
Group A: Model enhancement/testing and controls development	Spring 2024
Group B: Model & controls development/Construction	Spring 2024
Group A and B Phase II Test	May/June 2024

10. Project reports

10.1. Report File Names

To avoid extra work by the committee to rename all files, teams must use this convention for all reports:

Monthly Reports

Year-Month# University Name (abbreviated) Note: this is the competition year (spring term.

Example: for the October 2023 entry from the University of Drillbotics Competition (UDC)

Use: 2024-10 UDC

Design reports

Year University Name (abbreviated) Note: this is the competition spring term.

Example: for the 2023- 2024 entry from the University of Drillbotics Competition (UDC)

Use: 2024 UDC Phase I Design Report

10.2. Monthly Report Contents

Starting in October for the fall term, the student team shall submit to DSATS a short monthly project report that is no more than one page in length (additional pages will be ignored) due on or before the last day of each month. Send all reports via email to competition@drillbotics.com . The monthly report should include:

Phase I Monthly Report Contents

- Key project activities over the past month.
- Literature survey, rig modeling considerations, trade-offs, critical decision points etc.
- New or replacement team members or faculty supervisors (include their email address)
- Cost updates
- Significant new learning, if any

Phase II Monthly Report Contents

- Key project activities over the past month.
- Model enhancements, controls development updates.
- Preliminary results of exercising the drilling model and controls
- Cost updates
- Significant new learning, if any

10.3. Other items of interest

To teach students that their work involves economic trade-offs, the monthly report should include the economic basis of decisions for hardware or software. It should also include at a minimum a summary estimate of team member labor hours for each step in the project: modeling, controls, testing etc. and a cost summary for hardware and software related expenditures. Also include labor for non-students that affect the cost of the project. Labor rates are not considered, as to eliminate international currency effects. Labor is not considered in the cost limits of section 7.1 but should be discussed in the reports.

10.4. Phase I Design Report

Detailed requirements for each group are listed in their respective Appendix A.

10.5. Final report, presentation and paper

10.5.1. The finalists shall prepare a project report that addresses items specific to each Group. We suggest you use the format of most SPE papers. For reference, please see http://spe.org/authors/resources/. This report may be submitted up to four weeks after the final test.

10.5.2. Finalists shall prepare a pre-recorded presentation two weeks prior to the Phase II test. Judges will review the recording and prepare a list of questions for the Q&A session that precedes the final test. Numerous examples are available online at https://drillbotics.com/archives/ and our YouTube channel

https://www.youtube.com/channel/UCRTpKWHRiphNo6KeSqTcNyg

10.5.3. The reports, presentations, paper and all communications with DSATS shall be in the English language. The presentation must be made by at least one member of the student team, not the team supervisor.

11. Group A and Group B Prizes

11.1. The program committee of the Drilling Conference awarded the Drillbotics subcommittee a permanent slot[3] in one of the drilling sessions at the conference. As per SPE's customary procedures, the paper will be archived in OnePetro. In addition, SPE has agreed to furnish a booth[4] in the exhibition area during the conference where the team can erect their rig and describe its operation to the conference attendees. Alternately, Group A teams will have an opportunity to showcase their simulation model at the booth.

11.2. This is an excellent opportunity for students to network with the industry.

11.3. The winning team, as determined by the conference program committee, will be asked to submit a paper to present at the next SPE/IADC Drilling Conference.

11.4. The Drilling Conference program committee will choose either a Group A or Group B winner to present at the conference. Only at their discretion will the second group receive an invitation to present. The Drillbotics Committee may fund both teams travel if it holds sufficient funds, which will be determined a month before the Phase II test.

11.5. The winning team will receive a travel grant[5] to attend the Drilling Conference. Note that this is for a limited number of team members, not to exceed five (5) plus one (1) supervisor. Pre-approval of expenses is required.

11.5.1. Upon submittal to DSATS of a valid expense statement of covered expenses (typically a spreadsheet supported by written receipts) individuals will be reimbursed by the treasurer of DSATS for the following:

11.5.2. Round trip economy airfare for the team and one university sponsor/supervisor to the gateway city of the next SPE/IADC Drilling Conference. Entrants should use the SPE approved carrier where possible to minimize cost. Airfares that exceed the SPE rate must be pre-approved by the committee, or the reimbursement will be limited to the SPE rate. Information of reduced fare flights is available on the conference website. Please note that reservations must be made before the SPE published deadline. The departure point will be a city near the university, the student's home, or current place of work, subject to review by the Committee. Alternately, a mileage reimbursement will be made in lieu of airfare should

[3] Subject to continued approval by the conference program committee.

[4] Subject to continued approval by the SPE conference staff.

[5] Travel authorization will depend on any international or local travel restrictions in place at the time of certain events.

the entrants decide to drive rather than fly to the conference. The reimbursement is based on current allowable mileage rates authorized by the US Internal Revenue Service.

11.5.3. One rental car/van at the gateway city for those teams that fly to the conference.

11.5.4. Lodging related to one hotel room or housing unit[6] per team member will be reimbursed at a rate not to exceed the SPE rate. Note that the room reservations are limited, so entrants must book their rooms early. Room and taxes for the night before the DSATS symposium, the night of the symposium and for the nights of the conference are covered. Charges for the room on the last day of the conference need to be pre-approved by the Committee as most conference attendees depart on the last day of the conference unless there are unusual circumstances.

11.5.5. A per diem will be pre-approved by the Committee each year, which will vary with the cost of living in the gateway city. The per diem is intended to cover average meals (breakfast, lunch and dinner) and incidentals.

11.5.6. Conference registration will be reimbursed. Students should register for the conference at the student rate. Early registration is appreciated.

11.6. Individual award certificates will be presented to all participants upon request, with special certificates given to all finalists. Team members wanting a certificate should send an email to competition@Drillbotics.com with the spelling of their name as they wish it to appear on the certificate.

11.7. DSATS may provide additional awards, at its sole discretion.

11.8. The evaluation and all decisions on any matter in the competition by the Drillbotics judges and DSATS board are final.

12. Terms and Conditions

12.1. In no event will SPE, including its directors, officers, employees and agents, as well as DSATS members and officers, and sponsors of the competition, be liable for any damages whatsoever, including without limitation, direct, indirect, special, incidental, consequential, lost profits, or punitive, whether based on contract, tort or any other legal theory, even if SPE or DSATS has been advised of the possibility of such damages.

12.2. By entering this competition,

12.2.1. Participants and Universities agree to indemnify and hold harmless SPE, its directors, officers, employees and agents, as well as DSATS members and officers, and sponsors of the competition, from all liability, injuries, loss damages, costs or expenses (including attorneys' fees) which are sustained, incurred or required arising out of participation by any parties involved in the competition.

12.2.2. Participants and Universities agree and acknowledge that participation in the competition is an agreement to all of the rules, regulations, terms and conditions in this

[6] A housing unit could be a shared property from such sources as Expedia, Air B&B or similar entities.

document, including revisions and FAQs posted to the DSATS and Drillbotics websites (see section 3.1).

12.2.3. Winning teams and finalists must agree to the publication of their names, photographs and final paper on the DSATS web site.

12.3. All entries will be distributed to the Drillbotics Committee for the purpose of judging the competition. Personal information, such as email addresses will not be published, but could be divulged to other teams being copied on competition emails. Design features will not be published until all teams have been judged and a winner is announced. Previous years' submittals, reports, photos and similar documentation will be publicly available to foster an open exchange of information that will hopefully lead to faster learning for all participants, both new and experienced.

12.4. DSATS and the SPE cannot provide funding to sanctioned individuals and organizations per current US law or the laws of nations that may host local contests.

12.5. Participants must comply with all local laws applicable to this contest.

13. Marketing

13.1. Upon request, DSATS will provide a link on its website to all participating universities.

13.2. If university policy allows, various industry journals may send a reporter to witness the tests and interview students to publicize the project.

13.3. Drillbotics is now a registered trademark. According to international law, the proper reference is to use Drillbotics® instead of Drillbotics™. The trademark reference is only needed the first time Drillbotics is referenced.

13.4. Any team that wishes to use the trademark on signs, tee shirts, technical papers or for other purposes may receive a no-cost license upon request. Send the request by email to the committee at competition@Drillbotics.com. Upon completion of the license agreement, access to the files with the logo will be made available. Unfortunately, trademark law requires us to enforce this for everyone to maintain our trademark, so please ask for license before you use our mark.

Appendix A: Group A Project Definition

A> Phase I – Design Competition

a. Prepare a safety plan at the beginning of the project and update it continually as needed.

b. Consider how you will use Human Factors within your project to improve your team processes and interactions with your model. You should include such items as:

    i. Who are the operators of your drilling rig and how do their characteristics impact the design?

    ii. Which functions of your drilling rig will be automated, and which will be manual (refer to Ref. 2)?

    iii. How are you going to ensure that the operator remains 'in the loop' at all times?

    iv. The workflow that your drilling rig will follow (very important as this will guide your interface design).

    v. The control and feedback needs for your defined operators.

    vi. The 'concept' of your interface design. This can be as simple as a 'wireframe' drawing with pen and paper, but it should show an appreciation of Human Factors Relevant Good Practice (refer to the resources provided below).

c. Design Criteria

Teams must show the formulae used in their alrorithms. Provide a table of the design calculations used.

a) Design submittal by the students shall include:

    i. Engineering drawings of the rig concept, simulated mechanical and electrical and auxiliary systems, if any

b) Design notes and calculations

    i. All engineering calculations shall be included in the Phase I report, even if the rig is built using previous years' designs. This ensures that the 2022 team reviewed and understood the previous design assumptions and calculations.

    ii. Calculations should include each formula considered in the design, a reference that shows the origins of the formula, why is was chosen, what engineering assumptions were made, a definition of all variables and the values used in the calculation.

Example:

Buckling limit Euler's Equatio(1) cite a reference here or in the reference section of your design report

The critical buckling load, bcr, is calculated:

$Pbcr = \pi 2 * E * I / (K * L)^2$

$Pbcr$: Critical buckling load
E: Modulus elasticity of the aluminum drill pipe
I: Area moment of inertia
L: Length of the column

K: Column effective length factor (explain how you chose the appropriate k or n factor)

c) The report should include a table that summarizes ALL calculations.

Example

Parameter	Symbol	Calculated Results		Safety Factor	Max Allowable		Reference	(Other as needed)
		Field Units	Metric Units		Field Units	Metric Units		
Critical buckling load								
Burst limit								
Torque limit								
… Other								

d. 3D Steering Challenge:
   i. Determine the level of complexity you want for your model. Previous teams started with a plan to incorporate many complex features within their model but were unable to deliver a working system in time for the Phase II test. The committee suggests you start out with an overall plan that allows you to first create a working model and later add modules to increase its functionality and fidelity. Explain your choices.
   ii. Develop a model of the rig's equipment, drillstring, BHA and bit and model a directional well drilled through multiple targets. Teams may choose a two-dimensional well path or opt for a three-dimensional trajectory. Three targets will be provided just before the Phase II test with the third target in a different plane that requires a turn as well as a drop. There could even be a build to reach a shallower depth.
   iii. The interface should use the vocabulary of the D-WIS semantics standard. Please refer to https://d-wis.org/vocabulary-index/.
   iv. See Section B below for additional information.

e. Well Control Challenge:
   i. Review the OpenLab Drilling simulator (https://openlab.app/) application. This will be the simulator we will use for the well control challenge.
   ii. The interface should use the vocabulary of the D-WIS semantics standard. Please refer to https://d-wis.org/vocabulary-index/.
   iii. Teams will develop appropriate controls to detect and react to a well control issue (e.g. a kick).
   iv. Test cases will be provided to the teams to test their control algorithm prior to the Phase II test.

v. Teams will have to develop a user interface allowing the judges to monitor the drilling state.
vi. See Section C below for additional information.

f. Phase I Design Report

The design submittal by the students shall include:

i. Student Biographies
ii. Name
iii. Previous degree attained – major
iv. Current degree and expected graduation date (month/year)
v. Main area of contribution to the project
vi. Other information as deemed appropriate by the team
vii. A description of your safety plan that is appropriate for the project
viii. Your process for including human factors in the design and implementation of the model.
ix. Simplified engineering sketches or drawings of the rig concept, mechanical and electrical and auxiliary systems, if any, that explain your design assumptions. Teams should recognize that they should model the rig capabilities with realistic limits for surface equipment and downhole tools. Consideration of time delays and measurement errors that mimic realistic rig systems increase the fidelity of your model.
x. Where applicable, include any design notes and calculations regarding the rig, drillstring and other limitations for the particular modules used in your models. For example, if the model has a module to adjust drilling parameters to avoid buckling of the drillstring, show how you calculated the weight on bit limits.
xi. A block diagram/flowchart of the modeled control system architecture is required. Describe the key features. The response time of measurements, data aggregation and control algorithms should be estimated. Explain how individual measurements are used in the control code. Are they all given equal weight, and if not, what criteria is used to assign importance?
xii. Proposed user interface/data display that shows the progress of the model in real time.
xiii. Cost estimate and funding plan
xiv. A design summary video used to outline the design submittal not to exceed five (5) minutes in length. Videos shall be the property of the university, but DSATS shall have the right to use the videos on its websites and in its meetings or events.
xv. Key features for any models and control software. What drilling dysfunctions are modeled and how are they mitigated?
xvi. If you are modeling sensors, explain how specific sensors and sensor data is modeled. What did you learn from modeling sensors?
xvii. Proposed model for data handling, i.e., inherent time delays and uncertainty.

1. The speed or rate of time of the model versus the simulated drilling time. Is this continuous or can certain intervals be slowed as needed?
2. The Phase I design report should include a discussion regarding the major design concept as modeled (mechanical and otherwise) with respect to the feasibility for use on today's working rigs? If not, what would be needed to allow implementation?

g. Phase I Evaluation
   i. The judges will review the design reports and rank teams using the same criteria as the Phase II evaluation information below.
   ii. The results will be announced in mid-February with comments that teams may want to incorporate into their Phase II efforts.
   iii. The committee will advance as many teams as is economically possible as finalists for Phase II.

B> 3D Steering Challenge Design Criteria

a. Overview

Teams will create a digital twin of a full-scale rig of their choice to drill a directional well virtually. The Drillbotics committee will provide certain information in advance but will not provide the actual well targets until the day of the Phase II test. The following attached pages describe the directional objectives as well as the data/deliverables requirements. Scoring for the directional competition objective will be primarily based on how accurately the directional targets are intersected by the calculated well trajectory. An example of the criteria for scoring is included below.

The end goal is for teams to develop a virtual drilling model and a control model to drill a well virtually. The details in the sections below are some recommendations on what you will have to consider when building the virtual drilling model. You and your team will have to determine what physics of the drilling process you want to model. But keep in mind that the competition challenge is to drill a directional well virtually to specified targets.

1. Teams should list key rig equipment used in their model and describe any specific equipment limitations. For example, if the team uses a top drive for torque and rotation, indicate what model top drive is modeled. Consider items such as maximum torque at a specific RPM. Teams should understand if their model requests torque or speed in excess of the equipment limits it negatively affects the fidelity of their model.
2. The rig model will typically consist of a hoist, usually a drawworks with drill line on a drum, a top drive providing the torque and RPM. The RPM, Torque, and Hookload are measurements taken at the rig model and will be inputs into the Control System.
3. The downhole drilling system model should predict bit trajectory for given WOB, RPM, drive mechanism parameters (e.g. steering force, AKO angle), and rock strength – as a function of measured depth. While the teams are empowered to decide on the complexity of the simulation model, the minimum requirements are stated below.

4. Another consideration is the delays inherent in taking surveys. If your model assumes continuous surveys only available with high-speed telemetry systems, that should be stated in your list of assumptions. If you assume that the survey is coming from a MWD or RSS tool, use frequencies and intervals that are more realistic to those systems.
5. Consider the impact of survey errors and cumulative errors for your model to make it more realistic.
6. Determine the appropriate update rates for each cycle within your model. Depending on how simple or complex your design your system, this may be one rate for the entire model or you may have some modules running at a different rate. If so, explain how you manage the synchronization of time across various modules.
   a. Teams may choose to iterate based on time or depth, but they must ensure that survey course lengths are appropriate for the dogleg severities being surveyed. It's typically recommended to not have survey intervals exceed 10m-13m (30ft – 50ft) in length for accurate wellbore placement. This should be considered in the control scheme if time-based survey intervals are being used.
   b. If you include modules to introduce drilling dysfunction and mitigation techniques, you may increase the functionality of your overall model but risk not meeting the project timeline or ending up with stability issues with you model. Explain how you chose which items to include or exclude.
   c. If you do choose to simulate full-scale rig effects, explain what frequencies you selected appropriate for the dynamics of the drilling system both at surface and downhole. Or you may have chosen a simpler design just for lab use. Discussion of such choices should be included in the design report.
   d. If you choose to include alerts for equipment or drilling dysfunctions, consider a plan for managing alerts that inform the observer without overwhelming them with too many alerts. Consider some of the references in Appendix C.
   e. Additional optional items for the directional drilling option:

      i. If you choose a course that does not intersect with a target, but lies within an acceptable proximity to the target, explain your choice.
      ii. Since this is a directional drilling problem, be sure to include how simulated downhole data is used for steering and other drilling aspects? Judges are looking for a description of the principles being applied to directionally steer the wellbore and hit the required targets.

b. Objectives

1. Hit one or more targets at one or more vertical depth(s) and X/Y coordinates.
2. For the Group B competition, the starting directional plan to hit the targets will not require wellbore inclinations in excess of 30° from vertical, 15° change in azimuth, or 10" displacement (departure from the vertical axis at well center) The max displacement/inclination/azimuth are total/accumulated from the start to the end of the well path.

3. Please note: Teams should be prepared to drill any given trajectory within the specified parameters, so the coordinates will not be provided in advance of the test.

c. *Automation Requirements*

Drilling mode/survey mode switching must be automated (i.e. built-in survey interval and drill string movement for on/off-bottom, slide/rotation mode switching). Teams may select how many surveys, survey frequency, and whether surveys will be made on or off bottom. Displays should show when surveys are being taken.

d. *Steering*

a. Steering requirements (e.g. toolface direction, slide length) must be calculated autonomously
b. The steering model takes inputs from the Bit Model and BHA Model to predict trajectory. A control system will also interface with the Steering Model and update parameters (such as pad force, AKO orientation, WOB, RPM, etc) accordingly.
c. Orientation of steering mechanism must be calculated by the system and shown on the rig floor display.
d. An RSS or AKO motor BHA will be specified on the day of the Phase II test. Thus, the model should be capable of simulating both steering systems.

e. *Surveys*

a. Directional surveying process must be entirely autonomous
b. Survey qualification must be done autonomously, however secondary qualification/verification/override can be made by a human
c. Dogleg severity required to hit target(s), distance/direction to plan must be autonomously calculated at each survey station and shown on the rig floor display

f. *Deliverables Requirements (Magnetic surveying)*

a. All teams are required to provide a definitive directional survey (TXT, LAS, or CSV format) meeting the following minimum requirements:
b. Header info to include:
    i. Team/school name
    ii. Directional Survey Date
    iii. Well Center Coordinates (WGS84 Latitude & Longitude)
    iv. True Vertical Depth Reference (in depth units above block level)
    v. Grid Convergence
    vi. Geomagnetic model used (if applicable)
    vii. Magnetic declination applied (Geomagnetic model or in-field referenced)
    viii. Total Azimuth Correction
    ix. Magnetic field dip reference (Geomagnetic model or in-field referenced)
    x. Total magnetic field strength reference (Geomagnetic model or in-field referenced)
    xi. Error model associated with well trajectory (ISCWSA/OWSG error model or otherwise)

1. If non-standard error model is being used (i.e., formulas being modified and/or coefficients being changed), error model description (using standard variable/coefficient naming conventions) and justification must be included in project design

c. Minimum Curvature calculated trajectory (using appropriate survey station interval to accurately represent the drilled wellbore position)
   i. Each survey station is to include the following data:
      2. Measured Depth
      3. Inclination
      4. Azimuth (referenced to "block north")
      5. True Vertical Depth
      6. Northing (from well center)
      7. Easting (from well center)
      8. Dogleg Severity
   ii. Final survey station is to be an extrapolation to total depth at the bit

g. Plots

a. All teams are required to provide plan vs. actual plots containing the following minimum requirements:
b. As-drilled trajectory and original planned trajectory shown on same TVD vs.
c. Vertical Section plot
   i. Vertical section direction to be determined by well center-to-target bearing
   ii. As-drilled trajectory and original planned trajectory shown on same X/Y plot
   iii. Grid north reference to "block north"
   iv. [0,0] at well center

h. Data Logs

a. All teams are required to provide directional survey raw data logs containing the following minimum requirements:
b. Each log entry is to include the following data:
   i. Time stamp (containing year, month, date, hour, minute, second)
   ii. Sensor measured depth
   iii. Downhole sensor value(s) recorded
      - Sensor axes values
      - Calculated survey qualifier values
   iv. Accepted survey indicator (if log entry is an intended survey station)
      - If secondary (i.e., human) qualification is also used, both acceptance indicators must be shown

i. Formation Characteristics

   i. DSATS will furnish a formation model immediately prior to the Phase II test.
   ii. Teams should prepare in advance to import or manually enter the data, as they prefer.

iii. The formation model should be defined by rock type, UCS, and confining pressure. At each simulation step increment, the bit drills and extends the wellbore. While calculation of explicit contact forces with the wellbore are not mandatory, the build rate will still change due to newly formed wellbore geometry and changing rock strength. This phenomenon must be taken into effect accurately. Teams can assume a 2D wellbore and thus develop a 2D drilling propagation model. The format for the formation data will be provided in late November.

j. Targets

The targets will not be available until immediately prior to the Phase II test. However, the starting directional plan to hit the targets will not require wellbore inclinations in excess of 30° from vertical, 15° change in azimuth. Note: This is a maximum. Be prepared for much smaller build rates.

k. Trajectory

Teams shall choose their own trajectory to optimize the drilling, the well path and closeness to the given targets. This should be computed autonomously after the targets are manually entered. Limit the scope to 2-D for both the steering model as well as the formation model for BHA/bit deflection behavior.

l. Bit Model

i. The bit model can be as simple as the equivalent model of Pessier et al. (1992) with appropriate framework for steerability such as bit anisotropy and bit tilt such as Menand et al. (2012). Effect of key parameters such as gauge length, drilling efficiency (MSE-DOC relationship) should be included. Inclusion of bit wear effects is not mandatory. For the purposes of this challenge, the bit model provided is sufficient. If teams wish to use a different bit, the directional bit behavior modeling assumptions should be clearly stated. The implementation (or sub-models) should be verified against published data such as Menand et al. (2012).

ii. DSATS has provided the following bit model for the Phase II test.

1. Input:
    a. Formation Aggressiveness (provided by Contest),
    b. Bit Aggressiveness Factor between 0.7 and 1.3 (Contestants will select a bit with this value, which remains constant through the run.),
    c. Weight-on-Bit,
    d. Bit RPM,
    e. Drilling Efficiency (provided by contest, “Eff” = 0.35),
    f. Bit Diameter (“D”) (provided by Contest),
    g. Formation confined compressive strength (“CCS”) (provided by Contest according to a formation model/prognosis),

h. Side cutting factor (provided by Contest, a constant value associated with a particular bit. Different bits are more laterally aggressive than others. Teams will either be assigned a bit with a particular Side cutting factor, or be forced to choose among bits with different side cutting factors.), Side force (provided by the Team's drillstring model)

2. Output:
   a. Axial Rate of Penetration
   b. Lateral Rate of Penetration
   c. Bit Torque
   d. mu = formation_aggressivenss*bit_aggressiveness_factor;

   e. ROP = (13.33*RPM.*mu.*WOB)*(Eff)/(D*CCS); % [ft/hr]; Derived from Teale MSE concept (1965).
   f. TOB = D*(mu.*WOB)./36; % [ft-lbs]; Derived from Pessier and Fear, SPE 24584 (1992)
   g. ROP lateral = side_cutting_factor*side_force*RPM/(D*CCS); % [ft/hr]

iii. The bit model currently provided is:

```
function [ROP, ROPlateral, TOB] =
rop_tob_drillbotics(formation_aggressivenss,
bit_aggressiveness_factor, WOB,RPM,Eff, D, CCS,
side_force, side_cutting_factor)

%% This function predicts ROP, Lateral ROP of the bit,
and Bit Torque
% Output Variables, Units:
% ROP, [ft/hr] (axial ROP)
% ROPlateral, [ft/hr] (lateral ROP)
% TOB, [ft-lbs] (bit torque)

% Input Variables, Units:
% formation_aggressivenss, [ ] (drilling agressiveness,
Torque/WOB ratio
% which is heavily influenced by formation type. based
on paper by
% Pessier and Fear in SPE 24584 (1992)) Contest will
provide this.
% bit_aggressiveness_factor, [ ] (range from 0.7 for
unaggressive bits to
% 1.3 for aggressive bits) Contestants or contest will
choose a bit
```

```
% which will have an associated
bit_aggressiveness_factor.
% WOB, [lbs] (axial force on the bit)
% RPM, [RPM} (revolutions per minute of the bit)
% Eff, [ ] (drilling efficiency, usually 0.3 to 0.4)
% D, [inches] (bit diameter)
% CCS, [psi] (confined compressive strength of the rock)
% side_cutting_factor, [ ] (scaling factor for side
cutting aggressiveness
% of the bit)

mu = formation_aggressivenss*bit_aggressiveness_factor;

ROP = (13.33*RPM.*mu.*WOB)*(Eff)/(D*CCS); % [ft/hr];
Derived from Teale MSE
concept (1965).

TOB = D*(mu.*WOB)./36; % [ft-lbs]; Derived from Pessier
and Fear, SPE 24584
(1992)

ROPlateral = side_cutting_factor*side_force*RPM/(D*CCS);
% [ft/hr]

End
```

iv. If teams wish to provide their own bit model, please explain why they want a separate bit model and please provide the code at least three (3) weeks prior to the Phase II test.

m. Drillstring

i. Teams should specify the physical characteristics of the drillstring used in their analysis.
ii. The Drillstring may be represented by one or more models. These models will have to do the following:
iii. Calculate torque and drag for a 2D or 3D survey, with hook load, mud weight, drill string/BHA dimensions, sheave friction and variable friction factors along the wellbore as inputs. Using this data, the model will be able to predict downhole WOB and available torque at the bit, which will be used as input to the Bit Models.

iv. The Drillstring Model(s) must also calculate buckling conditions. Drilling ahead in simulation will not be allowed if the Drillstring is buckling at any point along the Drillstring.
v. The Drillstring Model(s) must be able to simulate torsional oscillations (slow ones, like stick slip). It must be made up of multiple torsional spring elements and have friction damping from wellbore contact. Bit behavior in different rocks and at different WOB/RPM settings will cause stick slip, and the Control System for the top drive must be able to counteract stick slip automatically when it appears.
vi. Please do not attempt to model lateral vibrations of the Drillstring or BHA.
vii. The BHA must be modeled so that contact force at the bit and bit tilt are computed to be used in the steering model. Generally speaking, 100 ft. of the BHA within the wellbore needs to be modeled in order for correct bit side force and bit tilt computations. The resulting behavior of drive mechanism should be modeled. The BHA should also (virtually) measure certain parameters (such as inclination, RPM, vibration etc.) and return to the surface or the control system. The bit-to-sensor distance as well as measurement frequency (i.e., intermittent vs continuous survey) should be configurable parameters in the design.
viii. Teams are not required, but may consider whether their model assumes that the pipe will be subject to the same radius of curvature as the well trajectory. Consideration should include drill pipe, connections and BHA (versus one continuous section of drill pipe). What are the external bending moments and forces? How will this affect stress/strain? The pipe clearance from the wellbore wall may allow it to have a less severe bend and the connection points would also influence the stress/strain of the pipe body. Another question is whether plastic deformation should be allowed?

4.

C> Well Control Criteria

a. Overview

Teams will use the OpenLab Drilling simulator (https://openlab.app/) as the model for the drilling process and develop appropriate controls to detect and control a well control issue.

i. We will package in a Docker container an OPC UA server with the D-WIS connectivity from which the students can connect to the OpenLab Drilling simulator.
ii. Each team will run the Docker image on their computer.
iii. Their program can access the local OPC-UA following the D-WIS interface and they can send set-points to the simulator and receive measurements from the virtual sensors on the simulator.
iv. The Docker image will make it possible to access a few different test cases.
v. The day of the competition, we will change the access to the simulator on one of the accessible test cases where we will have prepared a different drilling configuration.

vi. The trajectory, wellbore geometry, geo-pressure margins, drilling fluid characteristics, drill-string, available sensors at the rig will all be different for each of the available training cases and will be again different during the day of the competition. So the controls software shall rely on the D-WIS interface to discover which signals are available for each of the cases.

vii. The cases are centered around experiencing a kick during connection in water-based mud, i.e., analysis of the flow-back pattern when the mud pumps are turned off (and on). This is a typical scenario for a well control event for which the simulator will provide realistic responses. However, the responses are very different depending on the rig configuration, the length of the well, the compressibility and temperature of the mud, etc.

So, to summarize, the team's work will be to control the drilling machines (top-drive, hoisting, mud-pumps) to start drilling a stand, drill the stand and then start the connection procedure. The internal geopressured margins will be different from what the case describes and depending on how they have drilled the stand, they will get (or not) a kick with relatively variable appearance.

D> *General guidelines for both challenges (Well Control and 3D Steering)*

a. *Automated Drilling*

i. After initiating the model it should run until completion without human involvement. Remote operation and/or intervention is not allowed.

ii. Teams may choose the level of complexity for their model. The following is only one example of a typical control system that may include the following elements:

1. Drilling Optimization: Optimize set point commands for drilling parameters such as WOB, RPM, etc. such that drilling performance and steering are optimized (according to each team's definition of "optimized performance"). Such real-time optimization should be done automatically.
2. Trajectory Control: For the 3D Steering Challenge, steer the well according to the given well plan. The objective is both to minimize trajectory error and wellbore tortuosity. Virtual surveys should be acquired and be used as feedback for the steering control logic. Be prepared to model a push-the-bit RSS and a bent motor AKO. The steering model should include considerations for how often the survey is taken and how far from the bit the sensors are placed (e.g., projecting from the survey depth to the bit, and the control system using survey information to decide steering parameters).
3. Rig Display: Real-time display of the drilling parameters and wellbore positioning during the final testing is mandatory. End of well report immediately after the competition is mandatory.
4. Set Point Control: Although set point control, i.e., automatic control of drilling parameters as per optimal set points, is an integral element of the drilling systems, this competition does not make it mandatory to reduce complexity. It

can be assumed that the surface parameters such as WOB and RPM reach the BHA, making quasi-static modeling sufficient. However, the teams are encouraged to go "above and beyond" and demonstrate set point control independent of trajectory drilling. For example, the WOB and RPM control could be implemented for the virtual drill rig with a suitable mechanism for applying WOB (e.g., dead weight and drawworks), RPM (e.g., top drive), etc. Characteristics for each sub-system could be assumed realistically (e.g., top drive motor characteristics with RPM-torque relationship). Other examples include slide/rotate mode control.

b. *Coding*

i. The entire code should be written with a modular design with functions/subroutines for each sub-system. The drilling system model should be a separate application that interacts with the control system. Appropriate interfaces (APIs) should be developed for interoperability and deployment.

ii. Note that code for some modules is available on the website of the Open Source Drilling Community. Go to their GitHub page for the models. If teams use any of these models, please be sure to cite the source and give a brief explanation of how the model works and why you chose it. Also consider joining the community and eventually sharing your contributions.

iii. Teams are encouraged to share their code to promote the learning spirit. Such sharing can occur during or after the final presentations, or after securing any IP protection, at the discretion of the teams. However, release of codes is not mandatory and will not count towards the final score.

c. *Data visualization*

i. Teams must provide a display to observe the status of the model.

ii. Novel ways of presenting the data and progress of drilling in real time will receive particular attention from the judges.

iii. Visualization of any processes (automation, optimization, drilling state, etc.) should be intuitive and easily understood by the judges, who will view this from the perspective of the driller operating a rig equipped with automated controls.

iv. All depths shall use the industry-standard datum of rotary/kelly bushing interface (RKB), which should be the top of the rig's "drill floor."

d. *Phase I design Report*

i. Teams will submit a detailed report containing detailed literature review, model assumptions, overall plan of the virtual system, including the system architecture, different layers (such as data layer, control layer etc.), mathematical framework for modeling and control schemes, a plan for implementation, and relevant details. It is preferable to include a special section for the API, if other systems need to interact with your system. Preliminary results from the virtual drilling rig model should be included, along with a discussion on the results.

ii. There are numerous examples of previous reports on the Drillbotics website. Feel free to use this as a resource. Should a team choose to use the concepts in previous reports in their design, be sure to cite the source of the information to avoid plagiarism concerns.

E> Phase II – Drilling Competition

a. Phase II Activities

i. Teams will continue to develop and tune their models.

ii. Monthly progress reports are due at the end of each month.

iii. Teams will deliver a pre-recorded presentation for the Phase II test two weeks prior to the test:

1. The students will present a BRIEF summary of their final design, highlighting changes from their Phase I design, if any. Include an explanation of why any changes were necessary, as this indicates to the judges how much students learned during the design and construction process. Explain what *key* features have been deployed. Describe novel developments or things learned that were worthwhile. Also include how actual expenses compared with the initial estimate. At some time during your talk, let us know who the team members are and what background they have that pertains to the project. Try to include all your team members as presenters, not just one spokesperson. The committee wants to see if all team members have a good understanding of key issues.
2. Previous teams used a short PowerPoint presentation of about ten slides or so. Use any format you like.

b. Phase II Testing

i. In the spring term of 2022-2023, qualifying teams will present their model to efficiently drill a deviated well to hit the required targets while controlling drilling dysfunctions as the primary technical objective of the competition.

ii. The contest will begin with streaming of a pre-recorded presentation by each team. This will be followed by a period of questions and answers (Q&A) via on-line or in-person or a hybrid of both. Teams will draw lots to determine the order of presentation. All teams may sit in for the presentations and Q&A of the other teams.

iii. Depending on the time available, the actual test will start shortly after the last presentation of the day. It is possible that the presentations and tests could take two days to complete.

iv. While sharing of code is not mandatory, the presentations should include the details of the control schemes. Organizers can be contacted in case of any confidentiality requirements.
v. The drilling plan will be presented to the teams on the day of competition.
vi. The rock properties will be provided as a function of true vertical depth or measured depth at that time.
vii. An RSS or AKO motor BHA will be specified on the day of the competition. Thus, the model should be capable of simulating both steering systems.
viii. Drillbotics may provide data to calibrate sub-models such as the bit model. Additional details will be released during Phase II.
ix. **The teams are given a maximum of three hours to virtually drill the well**. Students are allowed to debug/modify the code and use multiple attempts within the allotted time.

c. Evaluation
   i. Teams will be evaluated on a per model basis. Points will be given for having each model or control system present and functioning in a realistic manner. A team that predicts the trajectory the best but is missing a model of the rig will earn fewer points than a team that has all the models and control systems from bit to rig. The purpose is to model the entire system and have the sub-models behave realistically.
   ii. The set point control is not a mandatory item for the competition. Any demonstration of such capability will attract extra points in "above and beyond" category.

Scoring of the 3D steering challenge will be primarily based on the following criteria, with the weighting of individual items as indicated:

Criteria	Metrics	Weight
Drilling system model	Does steering model consider steering method, geometry (e.g., projection-to-bit algorithm), bit side force/tilt, new wellbore, etc.? Are string elasticity, wellbore friction modeled?	30
Control scheme	Does trajectory control algorithm use realistic constraints? Does it use realistic virtual measurements? Does it consider surveying uncertainties and noise? Does the model utilize a re-planning to target process based on as-drilled surveys? Is basic drilling optimization algorithm implemented? Are rig controls simulated? (e.g., slide vs rotate)	30
The Virtual Drilling App	Features, modularity, and robustness of the app, real-time display, end of well report	20
Performance	Demonstration of the app and the degree to which drilling objectives are met	20

Bonus	Considerations above and beyond the minimum requirements that demonstrate thoroughness and creativity	10
	Maximum achievable score out of 100	110

Scoring of the well control challenge will be primarily based on the following criteria, with the weighting of individual items as indicated:

Criteria	Metrics	Weight
Control scheme	Does control algorithm use realistic constraints? Does it use realistic virtual measurements? Does it consider uncertainties and noise?	50
The Virtual Drilling App	Features, modularity, and robustness of the app, real-time display, end of well report	30
Performance	Demonstration of the app and the degree to which drilling objectives are met	20
Bonus	Considerations above and beyond the minimum requirements that demonstrate thoroughness and creativity	10
	Maximum achievable score out of 100	110

Drilling performance will be observed and measured by Drillbotics judges invited to attend and witness the test. This could be an in-person or virtual event depending on travel restrictions. The details will be announced in April 2022.

F> Final Report and Paper

The finalists shall prepare a project report that addresses the items below. We suggest you use the format of most SPE papers. For reference, please see http://spe.org/authors/resources/

a. The final report is simply an update following the Phase II test to explain what worked and what did not and to discuss future plans that would improve your design.
b. The winning team in Group A will need to start work on an abstract for their paper shortly after the Phase II test results are announced.
c. If the abstract is accepted, in August or September, the team needs to start writing their SPE paper. The abstract must generate sufficient interest with the SPE review committees to warrant publication, although DSATS will help promote acceptance elsewhere if necessary.

d. The timing for submission of the abstract and paper will be the published deadlines per the call for papers and conference guidelines as posted on the SPE's website (www.spe.org).
e. The paper should address at a minimum:
    1. The technical considerations for the model of the rig, its control system, drillstring including BHA and why certain features were chosen and why others were rejected.
    2. The setup of the experimental test, the results and shortcomings.
    3. Recommendations for improvements to the design and testing procedures.
    4. Recommendations for improvements by DSATS of the competition guidelines, scheduling and provided material.
    5. Areas of learning gained through the competition not covered in the university course material
    6. Note that the SPE audience already knows a lot of the background information that you presented the judges to demonstrate your capabilities, so adjust the paper content accordingly.

Appendix B: Automation & Interface Design from a Human Factors Perspective

Background on Automation

Any complex, engineered system that is wholly reliant upon human operators to achieve its goal is likely to experience issues. Humans are inconsistent when performing monitoring tasks, they tend to not make wholly rational decisions, are impacted by external factors and are prone to error. As technology advances and complexity increases (such as the control regimes proposed in remote drilling operations for example) such issues become more prevalent. However, many of the issues associated with such complexity can be countered by reallocating certain tasks to automation.

The concept that 'machines' (read automation) are better at some tasks than humans and vice versa has been prevalent for decades. The original incarnation of this notion was presented in 'Fitts List' [Ref. 1]. 'Fitts List' is 11 statements designed to provide guidance on 'what humans are best at' compared to 'what machines are best at' for example:

Humans surpass machines in respect to:

- 'Their ability to improvise and use flexible procedures'

Machines surpass humans in respect to:

- 'Their ability to handle highly complex operations i.e., to do many different things at once'.

Although Fitts List was originally published in 1951, the vast majority of the statements still ring true today (after all humans have changed very little in the last 70 years) but with advances in research and technology, automation is now viewed on a sliding scale (from wholly manual to wholly autonomous) This has recently been subject to consideration by the Drilling Systems Automation Roadmap who have chosen to adopt a 10-point level of automation taxonomy as follows [Ref. 2]:

1. The computer offers no assistance, and the human must do it all
2. The computer suggests alternative ways to do the task and the human selects from those suggestions and executes the task
3. The computer selects one way to do the task, which triggers five possible scenarios including:
    - the human executes that selection
    - the computer executes that suggestion if the human approves
    - the computer allows the human a restricted time to veto before automatic execution
    - the computer executes the suggestion automatically necessarily informs the human
    - the computer executes the suggestion automatically and informs the human only if asked

4. The computer selects the method, executes the task, and ignores the human.

Superficially, for highly complex systems, it may appear that there are very few downsides to providing very high levels of automation with little to no required user input. However, as is often stated, there is no such thing as a 'free lunch' and there are often overlooked downsides to providing high levels of automation usually termed the 'Ironies of Automation' [Ref. 3] which must be suitably managed. Two examples of this are:

1. Any autonomous system is ultimately conceived and designed by humans – Attempts to design out the human merely shift the responsibility further up the chain. Operators involuntarily inherit the biases and Performance Shaping Factors that influenced the design team.
2. The autonomous system cannot account for unforeseeable scenarios – This is one of the predominant reasons humans remain part of complex systems, to address the 'unknown unknowns'. However, expecting human operators to flip between a passive 'monitoring' role and an active 'doing' role is difficult to achieve, they may be 'out of the loop' and their Situation Awareness may be compromised.

Maintaining appropriate levels of automation and ensuring that your 'projected' drilling operator remains 'in the loop' through good interface design will be one of the key challenges you will face in the Drillbotics competition.

Resources

The following resources have been selected to assist you in the design of your drilling interface and the levels of autonomy you decide upon. Where possible free resources have been chosen (either available through OnePetro or elsewhere on the Internet) but two textbooks have also been selected as they offer an excellent primer on usability heuristics and the importance of good design.

1. de Winter JCF, Hancock PA. Reflections on the 1951 Fitts List: Do Humans Believe Now that Machines Surpass them? Procedia Manufacturing. 2015;3:5334–41.

Useful for reference, refer to Table 1 in particular for the original Fitts list.

2. Parasuraman R, Sheridan TB, Wickens CD. A model for types and levels of human interaction with automation. IEEE Trans Syst, Man, Cybern A. 2000 May;30(3):286–97.

Automation taxonomy chosen by the DSA.

3. HUMANFACTORS101. The Ironies of Automation [Internet]. Human Factors 101. 2020 [cited 2021 Sep 9]. Available from: https://humanfactors101.com/2020/05/24/the-ironies-of-automation/

A condensed version of the so called 'ironies of automation' as originally written by Lisanne Bainbridge.

4. Norman DA. The design of everyday things. Revised and expanded edition. New York, New York: Basic Books; 2013. 347 p.

A seminal text, a little dated in terms of examples but provides great insight into the impact of poor design.

5. Lidwell W, Holden K, Butler J. Universal principles of design: 125 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design ; [25 additional design principles]. rev. and updated. Beverly, Mass: Rockport Publ; 2010. 272 p.

An excellent 'style guide' to assist in designing your drilling interface.

6. Lauche K, Sawaryn SJ, Thorogood JL. Human-Factors Implications of Remote Drilling Operations: A Case Study From the North Sea. SPE Drilling & Completion. 2009 Mar 15;24(01):7–14.

Consideration of the implications of remote drilling operations from an impact on current work practices perspective.

7. Experience WL in R-BU. 10 Usability Heuristics for User Interface Design [Internet]. Nielsen Norman Group. [cited 2021 Sep 9]. Available from: https://www.nngroup.com/articles/ten-usability-heuristics/

A condensed take on a number of key usability heuristics.

8. Human factors/ergonomics – Alarm management [Internet]. [cited 2021 Sep 29]. Available from: https://www.hse.gov.uk/humanfactors/topics/alarm-management.htm

HSE background information on alarm management and prioritisation.

9. EEMUA Publication 191 Alarm systems - a guide to design, management and procurement. Available from: https://www.eemua.org/Products/Publications/Digital/EEMUA-Publication-191.aspx

This is a lengthy publication dedicated to alarm system design, will be useful for additional, wider reading. EEMUA membership is required otherwise the document requires payment.

10. Henderson J, Wright K, Brazier A, Great Britain, Health and Safety Executive. Human factors aspects of remote operation in process plants. Great Britain, Health and Safety Executive; 2002.

Useful background for wider reading.

11. Johnsen SO, Holen S, Aalberg AL, Bjørkevoll KS, Evjemo TE, Johansen G, et al. Automation and autonomous systems: Human-centred design in drilling and well. :150.

Report commissioned by the Petroleum Safety Authority Norway. Very comprehensive with some good case study examples included.

Appendix C: Additional References

a. Florence, F., Losoya, E., Drillbotics with Fred Florence and Enrique Losoya (2020, August 18), SPE Podcast, Link.

b. Pessier, R. C., & Fear, M. J. (1992, January 1). Quantifying Common Drilling Problems With Mechanical Specific Energy and a Bit-Specific Coefficient of Sliding Friction. Society of Petroleum Engineers. doi:10.2118/24584-MS

c. Menand, S., Simon, C., Gerbaud, L., Ben Hamida, M., Denoix, H. J., Cuillier, B., Sinardet, H. (2012, January 1). PDC Bit Steerability Modeling and Testing for Push-the-bit and Point-the-bit RSS. Society of Petroleum Engineers. doi:10.2118/151283-MS

d. Pehlivantürk, C., D'Angelo, J., Cao, D., Chen, D., Ashok, P., & Van Oort, E. (2019, March 4). Slide Drilling Guidance System for Directional Drilling Path Optimization. Society of Petroleum Engineers. doi:10.2118/194096-MS

e. Marck, J., Detournay, E., Perturbation to Borehole Trajectory across an Interface, ARMA-2014-7479, 48th US Rock Mechanics/Geomechanics Symposium, Minneapolis, Minnesota, June 1-4, 2014.

f. Zalluhoglu, U., Marck, J., Gharib, H., & Zhao Y. (2019) Borehole Propagation with Undergaged Stabilizers: Theory and Validation. ASME Journal of Dynamic Systems, Measurement and Control, vol. 141, no. 5: 051013. doi: 10.1115/1.4042380

g. Perneder, L., Marck, J. and Detournay, E., 2017. A model of planar borehole propagation. SIAM Journal on Applied Mathematics, 77(4), pp.1089-1114. doi: 10.1137/16M1094518

h. Zalluhoglu, U., Demirer, N., Marck, J., Gharib, H., & Darbe, R. (2019) Steering advisory system for rotary steerable systems. SPE/IADC Drilling Conference and Exhibition, 5-7 March, The Hague, The Netherlands. SPE-194090-MS, doi: 10.2118/194090-MS

i. Zalluhoglu, U., Gharib, H., Marck, J., Demirer, N., & Darbe, R. (2019) Steering advisory system for mud motors. SPE/IADC Drilling Conference and Exhibition, 5-7 March, The Hague, The Netherlands. SPE-194077-MS. doi: 10.2118/194077-MS

j. Franklin, G. F., Powell, J. D., Emami-Naeini, A., & Powell, J. D. (1994). Feedback control of dynamic systems, 3rd Edition, Reading, MA: Addison-Wesley.

k. Ogata, K. (2003). System dynamics, 4th Edition, Upper Saddle River, NJ: Prentice Hall.

l. Ogata, K. (2009). Modern control engineering, 5th Edition, Upper Saddle River, NJ: Prentice Hall.

m. Li, Y., Ang, K. H., & Chong, G. C. (2006). PID control system analysis and design. IEEE Control Systems Magazine, 26(1), 32-41.

n. Rawlings, J. B. (2000). Tutorial overview of model predictive control. IEEE control systems magazine, 20(3), 38-52.

o. Webinar: Machine Learning and Physics-based Solutions for Drilling Automation by SPE Distinguished Lecturer Prof. John Hedengren, Brigham Young University, YouTube Video.

p. Webinar: Drilling Automation and Downhole Monitoring with Physics-based Models. Link.

q. Video and Webinar Series: Understanding Control Systems by Mathworks. Link.