Society of Petroleum Engineers
Drilling Systems Automation
Technical Section (DSATS)
International University Competition
2020-2021

Drillbotics® Guidelines

Revised September 23, 2020

1. Introduction

This year marks the seventh 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. The university teams freely share 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.

This year's competition will be to create a virtual rig, including drill string/BHA and wellbore interaction, and to demonstrate the model using a control model developed by each team. Due to the COVID-19 pandemic, the Drillbotics challenge committee decided to focus this years' competition on a virtual rig in an effort to facilitate competition success while teams work together remotely. If school policies allow a team to design and build a physical rig and there are a sufficient number of teams capable of building a physical rig, the Committee will allow these teams to compete as a second group as mentioned below and referred to as Group B. The competition guidelines for the Group B competition is listed in Appendix C.

How did the competition first come about? (Florence et al., 2000). 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-

Version	Date	Section	Description
2021.01		All	Updated all sections to reflect virtual rig model+controls. Physical rig guideline is moved to appendix.
2021-02	23 Sept 2020	4.5	Removed restriction

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 2021 process.

Competition Overview:

- The challenge requires teams to develop a full-scale drilling system model, including its corresponding control scheme, to virtually drill a directional well following a given trajectory.
- The teams will design a control system that will virtually control the full-scale drilling system model to test and demonstrate the automated system. The teams should incorporate virtual downhole sensors, in addition to surface sensors in their automation and controls scheme.

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. They 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. Everyone must work collectively to establish functional system requirements, often fully understood by each team member to accurately model the drilling issues and create an integrated package working seamlessly together.

The oil and gas industry today seeks lower costs 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 yet about our business, we have a lot to learn about their fresh approach to today's problems. Good Luck!

SPE/DSATS Drillbotics® Committee

Challenge Team

Mike Attrell
Fred Florence
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Drillbotics Committee

DSATS

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Fred Florence	(Co-Chair)	Jayesh Jain	Victor Soriano
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Contents

Objectives for the 2021 Competition

1.1. During the school year beginning in the fall of 2020, a team of students will organize themselves to solve a drilling-related problem outlined in Section 3 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 and software 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. 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. All of this and more is needed to build and operate a complete automated drilling system.

1.2. The students could 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.

1.3. 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.

2. *Background*

2.1. What is DSATS?

2.1.1. 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 (http://connect.spe.org/DSATS/Home/).

2.1.2. 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. Any updates to the guidelines posted on the Drillbotics website via blog entries from the Committee are considered to be an official revision to these Guidelines. Questions and suggestions can be posted there, or teams can email the sub-committee at 2021@Drillbotics.com.

2.2. Why an international competition?

2.2.1. DSATS, as part of the SPE, is 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 Group A competition will receive a grant for economy class transportation and accommodations to attend the next SPE Drilling Conference and will present an SPE paper that will be added to the SPE archives of One Petro[1]. Winners of Group B will publicly receive recognition of their achievement and have the opportunity 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 help encourage student participation. Also, the practical experience with drilling automation systems increases the students' visibility to the companies that are leading automation activities.

3. Group A Competition Guidelines

3.1. Challenge overview for the 2020-2021 competition: The Group A challenge requires teams to 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. The Group A challenge does not involve building a rig or drilling system. The teams will design automation and control but will develop a virtual drilling system (i.e. computer models) to test and demonstrate the controls. Therefore, in addition to the guidelines specified below (Group A Competition Guidelines) in general, applicable guidelines from Appendix C (Physical Rig Considerations), should also be referred. While the teams will have to meet minimum competition requirements, any "above and beyond" work along the main theme will be rewarded additional points to encourage creativity and innovation.

3.2. Design: Since the challenge does not require rig construction, the scope of the design portion is limited. The teams are not expected to carry out detailed mechanical design of the rig but are expected to perform basic calculations for a realistic system. The scope includes selecting essential elements such as drive mechanism, drill pipe, BHA, surface systems for application of WOB and RPM, and other required components for the virtual system. Please refer to Appendix C for considerations for physical rig design.

[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 try to get the paper into OnePetro.

3.3. Modeling:

3.3.1. Rig model: The rig model will consist of a drum controlling the drawworks, a top drive controlling the torque and RPM. The RPM, Torque, and Hookload are measurements taken at the rig model and will be inputs into the Control System.

3.3.2. 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.

3.3.3. Bit model: 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 gage 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 will be provided.

3.3.4. Rock/wellbore: The rock 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.

3.3.5. BHA: 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 a configurable parameters in the design.

3.3.6. Steering Model: 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.

3.3.7. Drillstring: The Drillstring may be represented by one or more models. These models will have to do the following:

1. Calculate torque and drag for a 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.
2. 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.
3. 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 counter act stick slip automatically when it appears.
4. Please do not attempt to model lateral vibrations of the Drillstring or BHA.

3.3.8. 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).

3.4. Controls: The control system may include the following elements

*3.4.1.*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.

*3.4.2.*Trajectory Control: 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).

*3.4.3.*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.

*3.4.4.*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.

3.5. Coding:

3.5.1. 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.

3.5.2. 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.

3.6. Evaluation:

3.6.1. The drilling plan will be presented to the teams on the day of competition. The rock properties will be provided as a function of true vertical depth or measured depth. The teams are given 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.

3.6.2. 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.

3.6.3. Drillbotics may provide data to calibrate sub-models such as the bit model. Additional details will be released during Phase II.

3.6.4. 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.

3.6.5. 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.

3.6.6. 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.

3.7. Deliverables:

3.7.1. Phase I: 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 special section for the API, if other system need to interact with your system. Preliminary results from the virtual drilling rig model should be included, along with a discussion on the results.

3.7.2. Phase II: A deployable application that drills a directional well to a given trajectory plan using autonomous control of a virtual drilling system.

3.8. Useful resources:

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

3.8.2. 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

3.8.3. 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

3.8.4. 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

3.8.5. 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.

3.8.6. 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

3.8.7. 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

3.8.8. 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

3.8.9. 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

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

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

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

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

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

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

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

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

4. Team Members

4.1. DSATS envisions that the students would be at least senior undergraduate or Masters level, well versed in the disciplines needed for such a project. The maximum number of students per team is five (5) and the minimum shall be three (3). Any team that loses team members during the project can recruit a replacement.

4.2. At least one member of the 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.

4.3. 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.

4.4. 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.

4.5. Auniversity may sponsor more than one team in a group and may enter teams in one or both groups.

4.6. Students shall register their team not later than 1 November using the registration form on the Drillbotics website. Any changes to the team members or university supervisor over the course of the competition should be reported in the monthly reports.

5. Expenditures

5.1. Teams selected to advance to the second phase must limit the cost of the physical or virtual rig and materials to US$ 10,000 or its equivalent in other currencies. 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. DSATS shall not be liable for any expenditure other than DSATS provided material and specified travel expenses.

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

5.3. 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.

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

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

5.6. 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.

6. Other Considerations

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

7. Project Timeline

Phase I - Design:	Fall 2020
Submit monthly reports	On or before the final day of each month
Submit final design to DSATS	31 Dec 2020, midnight UTC
Submit an abstract to DSATS*	31 Dec 2020, midnight UTC

*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 – Model enhancement/testing and controls development	Spring 2021
DSATS to announce finalists	On or about 31 Jan 2021
Model & controls development/Construction	Spring 2021
Monthly reports	On or before the final day of each month
Final demonstration	The final demonstration will typically occur in late May or early June. Additional details on the logistics for the final demonstration will be shared in early 2021.

8. *Project report*

1.1.1. Starting in 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 it via email to 2021@Drilbotics.com. The monthly report should include:

1.1.2. Phase I

- Key project activities over the past month.
- Literature survey, rig modeling considerations, trade-offs, critical decision points etc.
- Cost updates
- Significant new learning, if any

1.1.3. Phase II

- Model enhancements, controls development updates.
- Preliminary results of exercising the drilling model and controls
- Other items of interest

1.1.4. Report content

1.1.4.1. To teach students that their work involves economic trade-offs, the monthly report should 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 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 item 6.1, but should be discussed in the report and paper.

1.1.4.2. Design reports must contain the following tables and place them in their design report appendices:

A. Student Biographies
   - Name
   - Previous degree attained – major
   - Current degree and expected graduation date (month/year)
   - Main area of contribution to the project
   - Other information as deemed appropriate by the team

B. Summary of Calculations, model details, controls algorithm etc.

9. *Evaluation Criteria*

9.1. DSATS will select an evaluation committee from its membership

9.2. Criteria/Weighting for Group A (see table below):

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

9.3. Phase II Criteria/Weighting for Group B (see table below):

Criteria	Parameter	Weighting
Phase I:		
a. Safety	Safety: construction and operation	10
b. Mobility of rig	Rig up, move, rig down	5
c. Design considerations and lessons learned		10
d. Mechanical design and functionality, versatility		25
e. Simulation/Model/Algorithm		25
f. Control scheme	Data, controls, response times	25
	Total	100%
Phase II:		
a. Creative Ability	Analysis, concepts, development	10
B .Engineering Skills	Problem/Goal, design criteria, feasibility	10
c. Construction Quality		10
d. Cost Control		10
e. Performance		30
Various parameters such as:	ROP, MSE, Landing Bit, Inclination, and other	
Are these used within the control algorithms		
Accuracy of drilled wellbore trajectory (see Appendix "A" for details)	Proximity of drilled wellbore to required target X/Y coordinates and vertical depths	
f. Quality of wellbore	Tested using the Go-No-Go flexible 'Casing'	10
	Verticality, tortuosity, caliper, other	
g. Data	Data handling, data visualization, data comparison to judges' wellbore logs, and other	20
h. Downhole Sensor Data Used in Control Algorithm	Pass/Fail	Pass/Fail
	Total	100%
Intangibles	Additional score may be added or subtracted by the judges at their discretion	

9.4. Group A Prizes

9.4.1. The winning team of Group A will be sponsored by DSATS to attend the next SPE/IADC Drilling Conference to present a paper that explains their project in detail.

9.4.1.1. The program committee of the Drilling Conference awarded the Drillbotics subcommittee a permanent slot 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 in the exhibition area during the conference where the team can erect their rig and describe its operation to the conference attendees. This is an excellent opportunity for students to network with the industry.

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

9.4.2.1. 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 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.

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

9.4.4. Lodging related to one hotel room 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.

9.4.5. 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.

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

9.4.7. Individual award certificates will be presented to all participants upon request, with special certificates given to all finalists.

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

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

9.5. Group B Prizes

9.5.1. The winning team of Group B may submit a SPE whitepaper that explains their project in detail. If the quality of the abstract is approved by the SPE Conference Program Committee, as per SPE's customary procedures, the paper will be archived in OnePetro

9.6. *Other prize information*

9.6.1. Individual award certificates will be presented to all participants upon request, with special certificates given to all finalists.

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

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

10. Final report and paper

10.1. 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/

10.2. The winning team of Group A shall update the report as needed to comply with SPE paper submittal guidelines to write a technical paper for publication by the SPE at its Annual Drilling Conference. SPE typically requires that the manuscript is due in the fall following the Phase II test. While the Drillbotics committee will make every effort to have the paper presented during the Drilling Conference, the SPE Program Committee has authority over which papers will be accepted by the conference. If the paper is not accepted by the conference, the Drillbotics committee will endeavor to have it presented at the DSATS Symposium and will use its contacts to have the paper published via other related SPE conferences.

10.3. The report, paper and all communications with DSATS shall be in the English language. The presentation will be made by at least one member of the student team.

10.4. The timing for submittal 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).

10.5. The abstract must generate sufficient interest with the SPE review committees to warrant publication, although DSATS will help promote acceptance where possible

10.6. The paper should address at a minimum

10.6.1. The technical details of the drill system model, assumptions and architecture. Results of the model prediction and discussion of the model results.

10.6.2. Details of the controls scheme, including block diagram and control algorithm. Challenges and trade-offs associated with use of specific control schemes.

10.6.3. Results of the final demonstration and discussion on future work/enhancements.

10.6.4. Recommendations for improvements by DSATS of the competition guidelines, scheduling and provided material.

10.6.5. Areas of learning gained through the competition not covered in the university course material.

10.6.6. A brief bio or CV of the team members and their sponsoring faculty.

11. Terms and conditions

11.1. 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.

11.2. By entering this competition,

11.2.1. 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.

11.2.2. 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 document, including revisions and FAQs posted to the DSATS and Drillbotics websites (see section 2.1).

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

11.3. All entries will be distributed to the Drillbotics Committee for the purpose of judging the competition. Design features will not be published until after 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.

11.4. DSATS and the SPE cannot provide funding to sanctioned individuals and organization per current US law.

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

12. Marketing

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

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

12.3. 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.

12.4. 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 2021@Drillbotics.com. Upon completion of the license agreement, access to the files with the logo will become available.

Appendix

A. Directional Objective Requirements

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.

<u>Objectives</u>

- Hit one or more targets at one or more vertical depth(s) and X/Y coordinates
- 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)

<u>Automation Requirements</u>

- 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)
- Steering requirements (e.g. toolface direction, slide length) must be calculated autonomously
    - NOTE: Steering mechanism can still require human intervention for placement and/or retrieval (e.g. whipstock) but orientation of steering mechanism must be calculated by the system and shown on the rig floor display.
- Directional surveying process must be entirely autonomous
    - Survey qualification must be done autonomously, however secondary qualification/verification/override can be made by a human
- 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

<u>Deliverables Requirements (Magnetic surveying)</u>

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

- Minimum Curvature calculated trajectory (using appropriate survey station interval to accurately represent the drilled wellbore position)
  - Each survey station is to include the following data:
    - Measured Depth
    - Inclination
    - Azimuth (referenced to “block north”)
    - True Vertical Depth
    - Northing (from well center)
    - Easting (from well center)
    - Dogleg Severity
  - Final survey station is to be an extrapolation to total depth at the bit

- All teams are required to provide plan vs. actual plots containing the following minimum requirements:
  - As-drilled trajectory and original planned trajectory shown on same TVD vs. Vertical Section plot
    - Vertical section direction to be determined by well center-to-target bearing
  - As-drilled trajectory and original planned trajectory shown on same X/Y plot
    - Grid north reference to “block north”
    - [0,0] at well center
- All teams are required to provide directional survey raw data logs containing the following minimum requirements:
  - Each log entry is to include the following data:
    - Time stamp (containing year, month, date, hour, minute, second)
    - Sensor measured depth
    - Downhole sensor value(s) recorded
      - Sensor axes values
      - Calculated survey qualifier values
    - 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

B. Safety

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. How the team communicates with each other before and during rig operations is also important. Judges will grade each team on its comprehensive safety case.

Because most of the rigs have equipment spinning at high RPMs, some form of protective cover must 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.

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

- OSHA Pocket Guide, Worker Safety Series: https://www.osha.gov/Publications/OSHA3252/3252.html
- OSHA Checklist for General Industry: http://www.scosha.llronline.com/pdfs/genind.pdf

C. Group B Competition Guidelines

The Group B competition is subject to number of teams that are interested in participating in automation of a physical rig. This Appendix C 1.0 (physical rig) replaces Section 3.0 (virtual rig) for those teams who wish to compete in Group B.

1.0. Physical Rig Considerations: 2020-2021 High Level Challenge and Judging Changes

1.0.1. Directional steering is a more critical part of the competition for 2021. (see **Error! Reference source not found.**~~3.5~~) The wellbore must be started vertically and then kicked off below a specified depth to hit multiple directional targets (at varying X/Y coordinates and vertical depths). Teams score more points based on how accurately each directional target is hit (see Appendix "A" for scoring details)

1.0.2. Downhole sensors are mandatory, and it is also mandatory to implement their data into the control algorithm of the rig. A severe penalty will be applied to teams who do not use downhole sensors. Closed loop control of the rig based on downhole data is mandatory in this year's competition and not integrating this data set into the control algorithm is considered a "F- Failing grade" in this year's competition.

1.0.3. A homogeneous sandstone Rock Sample will be provided by Drillbotics (see **Error! Reference source not found.**~~3.6~~) only if there is a Group B competition.

1.0.4. DSATS to provide a new bit only if there is a Group B competition. The bit will be 1.5" diameter and 2" length. Students are permitted to use their own drill bit for the 2021 competition. (see **Error! Reference source not found.**3.7)

1.0.5. Additional information regarding the judging of the competition is detailed in section 3.16.

1.1. Two Project Phases

Fall Semester 2020

The first phase of the project is to organize a team to design an automatic drilling machine to solve the project problem. It is not necessary to build any equipment in this phase, but it is okay to do so. Design considerations should include current industry practices and the team should evaluate the advantages and shortcomings of today's devices. The design effort may be assisted by university faculty, but the students are encouraged to introduce novel designs for consideration. The design should also include consideration for downhole sensor and the control system to automatically control the drilling process. The level of student, faculty and technical staff involvement shall be reported when submitting the design. For returning teams, the Phase I Design should include an analysis of data and learnings from previous ("offset") wells drilled.

Spring Semester 2021

During the second phase, the finalist teams selected by DSATS proceed to the construction and drilling operation will use the previous semester's design to build an automated drilling machine. As per industry practices, it is common during construction and initial operations to run into problems that require a re-design. The team may change the design as needed in order to solve the problem subject to section 3.34.3. Teams may use all or part of a previous year's rig.

See section 67 for detailed timeline information.

1.2. Phase I – Design Competition

Design an automated drilling machine in accordance with the rules below.

1.2.1. DSATS envisions a small (perhaps 2 meters high) drilling machine that can physically imitate the functionality of full-scale rig machinery. (Since the winning machines will be presented at the SPE conference, there may be height restrictions imposed by the conference facility, so machines that are too tall may not be allowed on the exhibit floor.) The machine will be the property of the university and can be used in future research and competitions. New and novel approaches that improve on existing industry designs are preferred. While innovative designs are welcome, they should have a practical application to drilling for oil and gas.

1.2.2. The drilling machine will use electrical power from the local grid not to exceed 25 horsepower. Lower power consumption resulting from energy efficient designs will receive additional consideration.

1.2.3. The design must provide an accurate and continuous measurement of Weight-On-Bit (WOB), inclination, azimuth, and depth; as well as other drilling parameters (see Appendix “A” for directional surveying-specific data requirements), that should be presented as a digital record across the period of the test. All depth related measurements shall use the rig floor as the datum, not the top of the rock (the offset between the rock surface and the rig floor must be adequately processed within the control algorithms). Appropriate statistical measurements should be made at frequencies and with an accuracy and appropriate frequency content for the dynamics of the drilling system both at surface and downhole. Discussion of such choices should be included in the design report.

1.2.3.1. Distinguish in all data and documentation the difference between Weight-On-Bit and Hook Load; be specific when referring to these parameters

1.2.4. The proposed design must be offered in Phase I of the project, but changes are allowed in Phase II, as long as they are reported to the Committee via students’ monthly reports. A summary of all significant changes, including the reason modifications were necessary, must be included in the students’ final report.

1.2.5. Design submittal by the students shall include:

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

1.2.5.2. Design notes and calculations

1.2.5.2.1. 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 2021 team reviewed and understood the previous design assumptions and calculations.

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 Equation (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)

1.2.5.2.2. The report should include a table that summarizes ALL calculations.

Example

Calculations	*Formula*	*Reference*	*Results*
Moment of Inertia	$I = \pi / 64\ (dp4 - idp4)$	*Thin wall approx. or ID/OD calc separately or other?* *List your reference*	*0.000546* $in4$
Buckling Limit	$Pbcr = \pi 2 * E * I / (K * L)^2$	*Euler's Eq*	*18.9* kg

1.2.5.3. Control system architecture. (The response time of measurements, data aggregation and control algorithms should be estimated.)

1.2.5.4. Key features for any models and control software.

1.2.5.5. Proposed data handling and display.

1.2.5.6. Specification for sensors, signal processing and instrumentation, (verifying their accuracy, precision, frequency response and environmental stability), including the methods planned for calibration before and after the Phase II testing.

1.2.5.7. Plan for instrumentation of sensors in the BHA, as well as a method to synchronize all measurements and utilize both the surface and downhole sensors for real-time control of the drilling process.

1.2.5.8. An explanation of the implementation of the output of the BHA sensors to improve the trajectory of the wellbore, drilling efficiency and other drilling concerns.

1.2.5.9. An explanation of the algorithm used to autonomously control the drilling rig based on the output of the BHA sensors

1.2.5.10. An explanation of the principles being applied to directionally steer the wellbore and hit the required targets (see Appendix “A”) with the intent to score the maximum amount of points

1.2.5.11. Cost estimate and funding plan

1.2.5.12. 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 rights to use the videos on its websites and in its meetings or events.

1.2.5.13. All design, construction and operation of the project are subject to the terms and conditions of section 10~~11~~.

1.2.5.14. A safety case shall be part of the Phase I design (see Appendix “B”). Include a review of potential hazards during the planned construction and operation of the rig, and for the unloading and handling of any rock samples or other heavy items. An example of a safety case will be posted on the Drillbotics.com website.

1.2.5.15. The Phase I design report should include a discussion regarding the major design features proposed (mechanical and otherwise) - are they scalable to today’s working rigs? If not, what would be needed to allow implementation?

1.2.5.16. The Phase I design report should include a discussion regarding the control scheme and algorithm - How is each individual measurement used in the control code? Are they all given equal weight, and if not, what criteria is used to assign importance? What is the expected response time of the control system’s key components? How will this affect equipment selection? The teams are encouraged to perform control simulations to verify the control scheme.

1.2.6. A committee of DSATS members (the Committee) will review the Phase I designs and select the top five (5) teams[2] who will progress to Phase II of the competition.

1.2.7. DSATS shall also award a certificate of recognition and publication on its website for the most innovative design. The design video will also be shown at the DSATS automation symposium at SPE conferences.

1.2.8. DSATS will not fund any equipment, tools, software or other material, including labor, for the construction of the rig. Student teams are encouraged to find external funding from industry participants and suppliers.

1.3. Phase II – Drilling Competition

1.3.1. In the spring term of 2021, qualifying teams will build the rig and use it to drill rock samples provided by DSATS. Drilling a deviated well to hit the required targets (see Appendix “A”), efficiently through the sample while controlling drilling dysfunctions is the primary technical objective of the competition. Scoring of the directional drilling component will be primarily based on the horizontal distance from the target coordinate at which each target vertical depth was intersected. The use of both surface and downhole measurements to control the drilling process in real-time is mandatory, failure to do so will result in a failing grade. To avoid disqualification due to a downhole sensor failure, redundant or immediately replaceable items should be part of the design and implementation. Time to replace a sensor will be added to the drilling time for calculation of ROP.

1.3.2. The teams are to use manual control to pre-drill a vertical pilot hole not more than 1” deep measured from the rock’s top face. This hole is to be drilled using the competition drilling rig. Location of this pilot hole will be marked on each sample by the committee at the intersection of two lines drawn from opposite corners of the rock sample.

1.3.3. Teams may use glue or use a mechanical fastener to attach a bell nipple or diverter housing to the top of the rock to allow connection of a flowline for return mud flow. The maximum allowable length of the bell nipple is 8 inches. If you use a fastener, be careful not to break the rock.

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[2] The number of finalists could be increased or decreased by the DSATS Board of Directors.

1.3.4. When the competition drilling begins, teams will be required to continue to drill the pilot hole vertically to the kick off point. The kick off point may be at any depth greater than 4” below the surface of the rock.

1.3.5. Navigation shall be done autonomously

1.3.5.1. Manual intervention to add and/or remove a steering mechanism (e.g. whipstock) is permitted, however the determination/calculation of the orientation setting of the mechanism is required to be autonomous and must be shown on the rig floor display during each steering mechanism manipulation activity. The time to change orientation will affect the team’s ROP calculation.

1.3.6. No lateral forces are allowed to be applied above the top face of the rock.

1.3.7. No forces are allowed to be applied external to the rock that will force the drill bit in a particular direction

1.3.8. External magnetic field effects from the drilling rigs will be present on the directional sensors used to drill the wellbore. The industry has accepted practice of magnetic ranging. This may be a technique worth investigating to improve the signal to noise of magnetic measurements

1.3.9. Once drilling commences, the test will continue until the drill bit exits the rock sample, or three (3) hours, whichever comes first

1.3.10. Drilling performance will be observed and measured by Drillbotics judges invited to attend and witness the test. This could be a virtual event depending on travel restrictions. The details will be announced in early 2021.

1.3.11. DSATS will judge the competitors primarily on their ability to hit the required targets as accurately (i.e. as close to target center at the given target vertical depth) as possible (see Appendix “A” for details)

1.3.12. The final test will be scheduled late in the school year.

1.4. Rock Samples

1.4.1. DSATS will prepare a set of nearly identical homogeneous sandstone samples appx. 12”W x 24”L x 24”H (30 x 60 x 60 cm) for the final demonstration

1.4.2. The rock sample will be homogeneous sandstone, and rock compressive strength values will be provided for the sandstone samples furnished by DSATS in early 2021. The Drillbotics committee will mark the surface of rock to indicate the well center where drilling will start. It will be located at the intersection of two lines drawn from opposite corners of the rock sample.

1.4.3. The university and/or students may acquire or produce at their own cost rock samples as needed to verify the design and allow students to practice using their machine prior to the test. Drilling of any samples provided by DSATS prior to Phase II testing is not allowed and could lead to disqualification, except for the pilot hole to be drilled at the test location.

1.5. Bits

1.5.1. Upon request, DSATS will send a bit to the finalist teams for use in Phase II. It is expected that the BHA and pipe will cause some difficulty, both for initiating drilling dysfunction and for sensor integration and data telemetry. The judges will look for creative concepts supported by sound reasoning showing an understanding of how the BHA, bit and drillstring function together, and how the downhole system measures, samples and transmits the drilling data.

1.5.2. Upon request, the bit shall be returned to the Committee following Phase II testing for reconditioning for use in future competitions.

1.5.3. One (1) PDC bit will be provided by DSATS to be used during the Phase II tests. For 2020-2021 the bit will be:

1.5.3.1. A micro-bit 1.5" in (38.1 mm) diameter and 2.0" in total length.

1.5.3.2. Low axial aggressiveness and high side aggressiveness (i.e. high bit anisotropy).

1.5.4. Students are encouraged to consider bit wear prior to the final test and its impact on drilling performance during the onsite testing. Based on prior competitions, bit wear should be minimal but some cutter damage is always possible.

1.5.5. Student teams may build or buy similar drill bits to test their design with the rock samples they sourced. The students must not engage any third parties or receive professional assistance in designing their own bit, however manufacturing can be performed by a third party.

1.5.6. For the final competition, the students may use the directional drill bit provided by DSATS or use their own bit design. However, the dimensions of their bits must not exceed 1.5 inches in diameter and 2 inches long. This provision is made to enable students to fully optimize the bit design for their specific directional system.

1.6. Drillpipe

1.6.1. Stainless steel tubing will be permitted for the competition. Preliminary typical tubing specifications for aluminum tubing are listed below to assist with the mechanical and electrical design of the rig.

1.6.2. The drill pipe specifications for the 2020-2021 competition are subject to change, but should be:

1.6.2.1. Round Aluminum Tube 3/8 inch diameter x 36 inches long; 0.049 inch wall or equivalent

1.6.2.2. The material from KS Precision Metals is a typical low alloy material: "Our Aluminum tubing with wall thickness of .035 or .049 is 6061 T6"

1.6.3. DSATS will not be providing tubing to the competition teams.

1.6.4. The use of a metric equivalent of the tubing is permitted.

1.6.5. Tubing is usually available from various hobby shops such as K-S Hobby and Craft Metal Tubing and via Amazon and other suppliers.

http://www.hobbylinc.com/htm/k+s/k+s9409.htm

1.7. Tool joints

1.7.1. Students may design their own tool joints as long as the design concept is included in the Phase I proposal.

1.7.2. Alternately, students may use commercially available connectors/fittings attached to the drillpipe using threads, epoxy cement or other material, and/or may use retaining screws if desired, as long as the design concept is included in the Phase I proposal.

1.7.2.1. A fitting used somewhat successfully in 2017 is available from Swagelock. In 2018, the winning team used a fitting from Vertex.

1.7.2.2. A fitting used successfully in 2016, but which did not work well in 2017, is available from Lenz (http://lenzinc.com/products/o-ring-seal-hydraulic-tube-fitting/hydraulic-straight-connectors) that uses a split-ring to allow a torque transfer across the fitting.

1.7.3. Students must state WHY they choose a tooljoint design in the Phase I proposal.

1.8. Bit sub/drill collar/stabilizers

1.8.1. It is expected that each team will design and build their own bit sub. Instrumentation of the bit sub is ideal for directional sensors.

1.8.2. Additional weight may be added to the bit sub, or surface weight/force (above the rock sample) may be applied to provide weight on bit and drill pipe tension

1.8.3. Stabilizers are permitted but will be limited in length at the discretion of the Challenge Committee. Advise the committee of your choice and why and include this in the Phase I design for committee consideration.

1.8.4. Students must add sensors to the drillstring but are not permitted to instrument the rock samples. They must have a smaller diameter than the stabilizers and bit by at least 10%. Please include design concepts in the Phase I design.

1.8.5. The addition of along-string sensors to measure vibrations, verticality and/or tortuosity or other parameters will receive extra consideration. They must have a smaller diameter than the stabilizers and bit by at least 10%.

1.9. Automated Drilling

1.9.1. Drilling automation should be considered a combination of data, control AND dynamic modeling so that the control algorithm can determine how to respond to differences between the expected and actual performance. Process state detection can often enhance automation performance. Refer to documents posted on the DSATS website for more information.

1.9.2. Once drilling of the sample commences, the machine should operate autonomously. Remote operation and/or intervention is not allowed.

1.9.3. All directional control operations should be autonomously controlled by the drilling rig

1.9.3.1. Manual intervention to add and/or remove a steering mechanism (e.g. whipstock) is permitted, however the determination/calculation of the orientation setting of the mechanism is required to be autonomous and must be shown on the rig floor display during each steering mechanism manipulation activity

1.9.3.2. Length and timing of drilling modes (e.g. switching from slide drilling to rotational drilling, initiating the directional surveying procedure at the appropriate survey interval), must be autonomously determined/calculated and controlled

1.9.3.3. Directional surveys acquired by the system need to be used as feedback for the steering control (and/or calculation of the steering requirements) logic.

1.9.4. Set-point commands for drilling parameters (WOB, RPM, ROP, etc.) should be optimized such that drilling dysfunctions are avoided, and drilling can be completed within the given time frame. Real-time optimization should be done automatically. The controllers need to ensure that the drilling parameters respond once the set points are altered.

1.10. Sensors

1.10.1. The team may elect to use existing oilfield sensors or may look to other industries for alternate sensors.

1.10.2. The team may develop its own sensors if so desired.

1.10.3. Sensor quality differs from data quality. Both are important considerations in this competition.

1.10.4. The final report shall address which sensors were selected and why. The sensor calibration process shall also be explained.

1.11. Data collection and handling

1.11.1. The team may elect to use standard data collection and recording techniques or may develop their own. Data handling techniques and why they were chosen should be described in the Phase I submittal.

1.11.2. The final report shall address which data systems were selected and why.

1.11.3. The observed response time of measurements, data aggregation and control algorithms should be compared to the Phase I estimates and published in the final report.

1.11.4. Describe how data is measured, aggregated, stored and retrieved. Describe calibration and data validation techniques used.

1.12. Data visualization

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

1.12.2. Visualization of the 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.

1.12.3. Data must be presented in a format that allows the judges to easily determine bit depth, elapsed drilling time, ROP, MSE, verticality/inclination, vibration, and any other calculated or measured variable used to outline the drilling rigs performance to the judges. Lack of an appealing and usable Graphic User Interface (GUI) will be noted to the detriment of the team.

1.12.4. 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."

1.12.5. An End of Well (EOW) report should be provided to the judges at the conclusion of drilling.

1.12.6. See Appendix "A" for directional surveying-specific data visualization requirements

1.13. Measure and analyze the performance

1.13.1. The drilling machine should react to changing "downhole" conditions to select the optimal drilling parameters for improved performance, as measured by the rate of penetration (ROP), mechanical specific energy (MSE), verticality, cost per foot or meter, and other standard drilling measures or key performance indicators. Adding parameters such as MSE, or similar features, to the control algorithms will receive special attention from the judges.

1.13.2. Design limits of the drilling machine shall be determined and shall be incorporated in the programming of the controls during the construction phase.

1.13.3. Downhole measurements from directional sensors are to be used for adjusting drilling parameters and control of drilling machines used to aid in directional drilling

1.13.4. The final report (see Clause **Error! Reference source not found.**~~3.19~~) shall outline drilling performance and efficiency criteria and measured results.

1.13.5. One of DSATS' goals is to promote plug and play capability to accelerate the implementation of drilling automation. A DSATS committee is preparing definitions and examples of proposed data communication protocols and interfaces. Once this is available, the Drillbotics competition will require the use of these standard protocols. This will not be a requirement for 2021 but it will be included in future competitions. Links to these standards will be added to the Drillbotics.com website when they are published.

1.14. The test well:

1.14.1. The location and logistics for the final demonstration will be announced in early 2021.

1.14.2. Prior to the commencement of the test, teams will attach a bell nipple per **Error! Reference source not found.**~~3.5.4~~. They will then manually drill the pilot hole not to exceed 1" deep.

1.14.3. When the test begins, the teams will start drilling autonomously by continuing to drill the pilot hole, keeping the wellbore as vertical as possible until reaching the kick-off point. All rigs start the drilling competition at the same time.

1.14.4. The teams will kick off from vertical at any depth below the 4" vertical surface hole

1.14.5. The teams will attempt to hit multiple targets (varying X/Y coordinates and vertical depths) by following a provided directional plan/trajectory. Directional objective scoring will be based on the accuracy of the target depth intersection (i.e. horizontal distance from the target coordinate at the given target vertical depth). Refer to Appendix "A" for additional directional objective details.

1.14.6. No lateral forces may be applied above the rock or to the rock.

1.14.7. Drilling will stop at 3 hours or when the last team exits the rock sample.

1.14.8. A closed-loop fluid circulation system is not required, but could be of advantage for directional drilling, the bit and machinery should be cooled with air or fluid/water if needed. The design of the fluid system, if any, should be included in the Phase I design.

1.14.9. The rock sample will be homogeneous and will be capable of aiding in closed-loop fluid circulation. Note that the rock samples will leak once the drillbit punctures a rock face, so a rig design that includes a containment system is required.

1.14.10. Casing must fit in the directional wellbore. The ability to "run casing" is the secondary judging metric. Judges will run a "flexible" casing used as a gauge of borehole quality

1.14.11. A rig move, walking or skidding is not required, but the mobility of the rig will be considered in the design phase. The chargeable weight of the rig is an important consideration by the judges. See 3.19.4.2.**Error! Reference source not found.**~~E~~ regarding how this is calculated.

1.15. Not included in the 2020-2021 competition

1.15.1. The drilling will not include automating the making or breaking of connections. If connections are necessary due to the rig and drillstring design, connections should be made manually, and the time involved with the connections will be included with respect to its effect on drilling performance (rate of penetration reduction).

1.16. Other Considerations

1.16.1. 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 (see Appendix B).

1.16.2. Construction of the 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.

1.17. Presentation to judges at Phase II Testing

1.17.1. 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 measurement and control features have been deployed. Describe novel developments or just something learned that was worthwhile. Also include how actual expenses compared with the initial estimate. (Previous teams used a short PowerPoint presentation of about ten slides or so. Use any format you like.) At some time during your talk, let us know who the team members are and what background they have that pertains to the project. Be sure 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.

1.17.2. Judges will ask questions to ascertain additional details about the design and construction process and to see if all team members have a reasonable understanding how all the various disciplines used for the rig design and construction fit together.

1.17.3. All teams may sit in for the presentations and Q&A of the other teams. The order of presentation will be determined by drawing lots.

1.18. Project report

1.18.1. Starting in 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 it via email to 2021@Drilbotics.com. The monthly report should include:

1.18.2. Phase I

- Key project activities over the past month.
- Rig design criteria, constraints, tradeoffs, and how critical decisions were determined
- Cost updates
- Significant new learning, if any

1.18.3. Phase II

- Construction issues and resolution
- Summary of recorded data and key events
- Drilling parameters [such as WOB] and how they impact the test
- Other items of interest

1.18.4. Report content

1.18.4.1. To teach students that their work involves economic trade-offs, the monthly report should include at a minimum a summary estimate of team member labor hours for each step in the project: design, construction, testing, reporting, 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 item 6.1, but should be discussed in the report and paper.

1.18.4.2. Design reports must contain the following tables and place them in their design report appendices:

B. Student Biographies

- Name
- Previous degree attained – major
- Current degree and expected graduation date (month/year)
- Main area of contribution to the project
- Other information as deemed appropriate by the team

C. Summary of Calculations (list these at a minimum, list other is a similar format)

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. Power Consumption (rename devices as appropriate)

Device	Voltage	Current	Estimated		Single or Three ϕ	(Other as needed)
			HP	Watts		
Rotation						
Hoist						
Pump						
… Other						
Controls						
Displays						
…						
Total						

E. Diagram showing maximum dimensions of rig when operational (Include all auxiliaries) [Needed to determine size of display area as the Drilling Conference and confirm the height is within the limits imposed by the conference organizers]

F. Chargeable Weight of Rig (include shipping crates/boxes for rig and auxiliaries)

- The Chargeable Weight of Freight shipments are calculated as the Actual Weight (Gross Weight) or the Volumetric (also called Volume or

Dimensional) Weight of the shipment, whichever is the greater. This uses an estimated weight that is calculated based on the dimensions (length, width and height) of a package (shipments are always shown in the order of L x W x H). Typically, large items with a light overall weight take up more space on an aircraft than a small, heavy item. That's why the shippers charge according to Chargeable Weight.

- Multiply the length by the width by the height (L x W x H) in inches to obtain the cubic inches, then:
- To obtain the dimensional weight in pounds using inches, divide the cubic inch result by 166
- To obtain the dimensional weight in kilograms using inches, divide the cubic inch result by 366
- Using Dimensions in Centimeters: To obtain the dimensional weight in kilograms using centimeters, multiply the length by the width by the height (L x W x H) in centimeters and divide the result by 6000

1.18.5. File naming convention

1.18.5.1. To avoid extra work by the committee to rename all files, please use this convention for:

1.18.5.1.1. Monthly reports
Year-Month# University Name (abbreviated)
(note this is the competition year (spring term))
Example 2021-09 UDC

1.18.5.1.2. Design reports
Year University Name (abbreviated)
(note this is the competition year (spring term))
Example 2021 University of Drillbotics Competition

1.19. Final report and paper

1.19.1. 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/

1.19.2. The winning team of Group B is encouraged to update the report as needed to comply with SPE paper submittal guidelines and to submit a technical paper for publication by the SPE at its Annual Drilling Conference. SPE typically requires that the manuscript is due in the fall following the Phase II test.

1.19.3. The timing for submittal 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).

1.19.4. The abstract must generate sufficient interest with the SPE review committees to warrant publication, although DSATS will help promote acceptance where possible

1.19.5. The paper should address at a minimum

1.19.5.1. The technical and economic considerations for the control system, rig, and BHA design, including why certain features were chosen and why others were rejected.

1.19.5.2. The setup of the experimental test, the results and shortcomings.

1.19.5.3. Recommendations for improvements to the design and testing procedures.

1.19.5.4. Recommendations for improvements by DSATS of the competition guidelines, scheduling and provided material.

1.19.5.5. Areas of learning gained through the competition not covered in the university course material.

1.19.5.6. A brief bio or CV of the team members and their sponsoring faculty.