



Drillbotics 2027

Competition Guidelines

Society of Petroleum Engineers
Drilling Systems Advancement Technical Section
International University Competition

Mode Virtual V and Mode Physical P

2027 edition
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Revision: v1.2 | 23 October 2026

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1 Competition overview

Design, simulate, and control a virtual drilling system using standardized interfaces. Mode Virtual (V) emphasizes closed-loop control, data semantics, and clear reporting over hardware.

Build and operate a small-scale drilling rig that autonomously drills a directional well. Mode Physical (P) emphasizes safety, robust hardware, closed-loop control using downhole data, and clear reporting.

These guidelines cover Mode Virtual (V) and Mode Physical (P) for the 2027 competition. The Physical Rig Challenge uses a predefined build–drop–hold trajectory, issued three months before the physical competition. This requirement does not apply to Mode Virtual. Scoring uses the category weights in Section 4 and the scoring sheets at the end of this document.

1.1 Publication and clarifications

The committee will issue the approved guidelines as a dated PDF. Teams should use the latest issued PDF together with any numbered, dated clarifications issued by the committee.

To request a clarification, email competition@drillbotics.com. Include the guideline edition and section number, quote the passage, and state the specific question. Each official clarification will identify its number, issue date, affected section, answer and any affected package version. Changes to requirements, the schedule, the trajectory package or the scoring sheet will be communicated to all registered teams.

1.2 Competition phases

Phase I — Design: monthly updates plus a design report. Optional: a design-summary video of no more than five minutes.

Phase II — Implementation and testing: enhance the model and controllers; final test occurs at the end of the cycle.

Mode Physical (P): model and controls development and rig construction.

2 General competition requirements

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.

- 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.
- 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.
- While the teams will have to meet minimum competition requirements, especially innovative contributions are assessed using the total-score multiplier of up to 1.25 in Section 11.
- 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.
- 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.

2.1 Team members

- 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. Travel support, including the participant limit for single- and two-university teams, is governed by §14.1.
- 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 the collaboration rule in this section)
- 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.
- 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.
- A university may enter more than one team in a group and may enter teams in one or both groups.
- 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. Travel support, including the participant limit for single- and two-university teams, is governed by §14.1. Note: Any differences with intellectual property ownership between the two schools must be settled by the teams and shall not involve DSATS.

Register the team by the 2027 deadline announced by the committee and identify the competition mode. Case selection is not required during registration.

2.2 Expenditures

- 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. The annual US\$10,000 limit applies to eligible hardware, software and

materials. Student and non-student labor hours must be reported but are excluded from this limit. 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.

- 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.
- 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.
- Any team spending more than US\$ 10,000, or its equivalent in other currencies, may be penalized for running over budget.
- DSATS reserves the right to audit the team’s and university’s expenditures on this project.
- 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.

2.3 Faculty and outside assistance

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

2.4 General rules and interoperability

- Eligibility and team composition follow Section 2.1; cite all external sources and code. Publishable artifacts are encouraged (see Section 10 and OSDC references).
- Submissions **MUST** include required datasets and documentation. Submit `drilling_timeseries.csv` at ≥ 1 Hz using the committee-issued, versioned template, preserving its exact column names and units and following its documented missing-data rules. A static LAS 2.0 log is optional; omitting it does not reduce the attainable score.
- Interoperability checks are **REQUIRED** prior to final tests. For **Mode Physical (P)** these are read-only/shadow (**no PLC writes**). For **Mode Virtual (V)**, verify OpenLab API connectivity.
- Safety and compliance are **MANDATORY**. Judges grade both the plan and implementation.
- Outcomes-first and algorithm-agnostic: judges score outcomes and evidence; no preference is given to specific algorithms or model families (e.g., PID vs MPC vs RL; CNN vs rules vs LLM), provided constraints and safety are met.

Mandatory Rule

- Teams **MUST** pass interoperability checks before Phase II testing.
- Mode P interop is read-only/shadow; teams **MUST NOT** write to PLCs/actuators during checks.
- Safety compliance **SHALL** be demonstrated in both documentation and implementation.

3 Safety

Baseline expectations that apply to all teams, venues, and modes.

- Lab conduct and supervision: follow institutional policies; ensure adequate oversight for any powered testing.
- Electrical and mechanical safety: enclose rotating parts; provide guards/shields; use appropriate fusing, grounding, and LOTO where applicable.
- Emergency stops and interlocks: clearly labeled, tested E-Stops are **REQUIRED** for physical equipment; verify interlock behavior before demos.
- Procedures and training: maintain a written **Safety** plan; brief the team before each test; log incidents and near-misses.
- Data privacy and OpSec: keep credentials and control endpoints private; **DO NOT** expose unsafe remote control pathways. **DO NOT** commit secrets to public repos.
- AI and automation: any AI components **MUST** run offline for judging; **MUST NOT** write to PLCs/actuators during read-only/shadow interop checks.

Mandatory Rule

- Teams **MUST** maintain a written Safety plan and review it before tests.
- Rigs **MUST** have clearly labeled, tested E-Stops and appropriate interlocks.
- Mode Physical interoperability checks are read-only/shadow; teams **MUST NOT** write to PLCs or actuators during those checks.

Prohibited

- **DO NOT** expose remote control pathways on public networks.
- **DO NOT** commit credentials, tokens, or secrets to public repositories.

Recommended

- Log incidents and near-misses and include lessons learned in reports.
- Keep AI components small and edge-deployable; run offline during judging.

3.1 Physical equipment and risk assessment

Key expectations:

- Safety plan: identify foreseeable hazards and mitigations beyond PPE, including handling rock, rotating machinery, electrical shock, and communication during operations. Keep the plan current throughout the project.
- Guards and interlocks: rigs often spin components at high RPM; include protective covers/shields so loose parts cannot become projectiles. Provide emergency stops and appropriate interlocks.
- Lab practices: supervision, lockout/tagout where applicable, and safe test procedures.

Mandatory Rule

- Teams **MUST** maintain an up-to-date written Safety plan.
- Rigs **MUST** include guards/shields, appropriate interlocks, and clearly labeled, tested E-Stops.
- Operations **SHALL** follow institutional lab policies and supervision requirements.

Recommended

- Document hazard analyses and mitigations; update after each test.
- Practice lockout/tagout (LOTO) where applicable and train operators.

Judges may decide to deny a team from competing if their design is unsafe. Similarly, Mode Virtual (V) teams may be excluded if they have not met proper health and safety considerations.

4 Scoring and judging

Outcomes-first and algorithm-agnostic: judges score outcomes and evidence; no preference is given to specific algorithms or model families (e.g., PID vs MPC vs RL; CNN vs rules vs LLM), provided constraints and safety are met.

The following category weights apply to the 2027 competition. Sections 11 to 13 provide the assessment method, measurement specification, and scoring sheets.

4.1 Mode Virtual category weights

Category	Maximum points
Trajectory / Test / Target Accuracy	25
Drilling Efficiency (Time to TD / ROP)	25
Well-Control & Dysfunction Handling	15
Safety & Compliance	10
Human Factors & UI Clarity	10
Automation Quality & Innovation	15
Base total	100
Edge-AI Bonus (Optional)	+10 max

4.2 Mode Physical category weights

Category	Maximum points
Trajectory / Path Quality / Tortuosity	20
Drilling Efficiency (Time to TD / ROP)	20
Safety & Procedure Compliance (E-Stop, Guards, Limits)	20
Data Quality: required CSV, calibration, sampling rate and semantic metadata; LAS assessed only if submitted.	10
Human Factors & UI Clarity	10
Design & Automation Quality	20
Base total	100
Edge-AI Bonus (Optional)	+10 max

4.3 Innovation multiplier

Especially innovative approaches may receive an innovation multiplier on the total point count. The multiplier is applied once, after the category points and eligible bonus points have been added, and may be up to 1.25. The evidence requirements and calculation are set out in Section 11 and recorded on the scoring sheet.

Innovation may concern hardware, sensing, control, safety, human factors, data handling, or computational efficiency. Credit depends on demonstrated benefit rather than the name or complexity of an algorithm. The base score remains out of 100 points.

Optional tilted rig bonus

Physical teams may earn bonus points for starting the well with a tilted rig under the optional challenge in Section 8.7. These points are added to the total point count before the innovation multiplier. The

committee will publish the approved point values, maximum bonus and evidence thresholds in a separate, versioned rubric before teams commit designs. Release and version requirements are set out in Section 11.2.

4.4 Optional Edge AI bonus

Scored on correctness vs ground-truth windows, grounding to CSV, latency/footprint, clarity/safety, and innovation. AI score is scaled to a maximum of +10 points.

The optional Edge-AI bonus is capped at 10 points for 2027. Awarded bonus points are included in the total before the innovation multiplier is applied. The unmultiplied base category total remains 100 points.

- Expectation: focus your effort on generating/fine-tuning data and optimizing compact multimodal models.
- Inference-only, offline, JSON outputs (e.g., Explain-This-Event or Rig-State Textualizer).
- Small-model, edge-deployable focus: teams may prototype with larger cloud-hosted models during development, but final deliverables and performance are evaluated using locally run or on-rig small models under limited inference hardware.
- Suggested caps: ≤ 2 vCPU or ≤ 20 W GPU, ≤ 4 –8 GB RAM (non-LLM) and ≤ 8 vCPU or $\leq 1,150$ W GPU, ≤ 16 –64 GB RAM (LLM); ≤ 15 min total inference runtime. Rig compute otherwise open. All AI runs must be offline during judging; no PLC/actuator writes.
- Custom task option: teams may propose a custom offline JSON task with objective ground truth and the same interface for pre-approval (approval deadline to be announced for 2027). Approved tasks use the same AI sub-rubric and scale to +10.

5 Physical rig predefined build drop and hold trajectory

For the Physical Rig Challenge only, the committee will provide a predefined reference trajectory containing a build section, a drop section, and a hold section, in that order, with at least two targets and an azimuth turn. The trajectory will be provided to all Physical teams three calendar months before the physical competition. Teams must follow this reference trajectory rather than select a different scoring trajectory.

In the build section, inclination increases toward the specified inclination. In the drop section, inclination decreases toward the next specified inclination. In the hold section, inclination and azimuth are maintained at the values specified in the trajectory package. The package defines any initial vertical interval and the measured depths at all transitions. The kickoff point (KOP) and first target establish the initial vertical steering plane. The second target lies outside that plane, so the rig must change azimuth to reach it.

All Physical teams will receive the same trajectory package and scoring criteria. The predefined build–drop–hold requirement does not apply to Mode Virtual. Virtual teams may plan and autonomously replan their trajectory to meet the objectives, targets and constraints of their issued Virtual case.

The trajectory package will include the start point, datum, coordinate system, azimuth reference, units, measured-depth stations, inclination and azimuth, true vertical depth and horizontal coordinates, the KOP, transition depths, final depth, at least two target locations and their steering planes, dogleg limits, and acceptance tolerances. The committee will issue the numerical trajectory package three calendar months before the physical competition and announce the corresponding release date and time zone.

Physical teams may use autonomous steering corrections and replanning to return the drilled path to the reference trajectory. They must not change the reference path or scoring targets. Teams must retain the issued plan in plan-versus-actual plots and identify the package version in their data and scoring sheet.

For Mode Physical, the existing envelope remains: the starting plan will not require inclination above 30 degrees from vertical, an accumulated azimuth change above 15 degrees, or displacement above 10 inches from the vertical axis at well center. The committee will specify the actual build, drop, and hold parameters within this envelope.

Trajectory item	Definition to be issued
Reference and start	Datum, units, north reference, well center, initial vertical interval and KOP
Build section	Start and end measured depth, inclination, azimuth, build rate and limit
Drop section	Start and end measured depth, inclination, azimuth, drop rate and limit
Hold section	Start and end measured depth, constant inclination and azimuth
Targets and total depth	At least two targets in different vertical steering planes; azimuth turn; coordinates, depth references and target acceptance windows
Scoring measurements	Path deviation, target error, tortuosity and survey comparison method
Limits and tolerances	Dogleg limits, allowed deviation, survey station interval and uncertainty treatment

6 Reports and submissions

6.1 File names and submission

Use “YYYY-MM SchoolAbbrev” for monthly reports, with the actual report month, for example “2026-10 UDC”. Use “2027 SchoolAbbrev Phase I Design Report” for the design report. Submit reports to competition@drillbotics.com unless the committee issues another submission method.

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

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 2.2 but should be discussed in the reports.

6.2 Phase I package

Monthly reports, Phase I design report (and optional video), and a Phase II package with data, plots, and a short presentation.

Optional: a design-summary video of no more than five minutes. 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.

Mode-specific design report requirements are in Sections 7 and 8. Include a safety plan, design assumptions and calculations, control architecture, human factors, cost estimate and funding plan, and preliminary test results.

The Human Factors checklist in Section 7.3 applies to both modes: identify the operators, allocate automated and manual functions, keep the operator informed, define the workflow, establish control and feedback needs, and develop the interface concept.

6.3 Final presentation and report

Pre-recorded team presentation: submitted approximately one week before the test; judges prepare Q&A from it.

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.

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.

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. The final report should outline drilling performance and efficiency criteria and measured results.

The paper should address at a minimum:

- The technical and economic considerations for the control system, rig, and BHA design, including why certain features were chosen and why others were rejected.
- The setup of the experimental test, the results and shortcomings.
- Recommendations for improvements to the design and testing procedures.
- Recommendations for improvements by DSATS of the competition guidelines, scheduling and provided material.
- Areas of learning gained through the competition not covered in the university course material.
- A brief bio or CV of the team members and their sponsoring faculty.
- 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.

Teams invited to prepare a conference paper should begin their abstract after the results are announced. Publication is subject to abstract acceptance. Abstract and paper deadlines follow the applicable conference call for papers published by SPE.

- 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.
- Previous teams used a short PowerPoint presentation of about ten slides or so. Use any format you like.

6.4 Common data package

Telemetry dataset: fixed-schema drilling_timeseries.csv (≥ 1 Hz; D-WIS names) with semantic headers and units for apples-to-apples scoring.

Static logs (optional): LAS 2.0 wellname_logs.las with the applicable curves and metadata. Omitting an optional LAS file does not reduce the attainable score.

The CSV column set is defined by the committee-issued, versioned template. Preserve its exact column names and units. Where a mode or case lacks a signal, follow the template's documented missing-data rules and document the reason. Additional case-specific signals must retain clear names, units, and time alignment.

7 Mode Virtual requirements

7.1 Virtual competition case

One virtual case: details to be announced. Case selection is not required during registration.

New team Start here

Most first-time teams are successful by starting with the OpenLab Drilling Simulator and focusing on the control system and data handling, rather than building a simulator from scratch.

7.2 Interfaces and technical specifications

Connectivity Discovery D WIS OpenLab

- Use the D-WIS semantics vocabulary for signal names/metadata: D-WIS Vocabulary Index.
- Drillbotics provides a Dockerized OPC-UA server exposing D-WIS-named nodes connected to the OpenLab Drilling Simulator.
- Your control app connects to the local OPC-UA endpoint, writes setpoints, and reads measurements through the D-WIS interface.
- Day-of change: endpoint parameters and available signals may change; software must browse/discover and adapt to the active case.

Design for Discovery

- **MUST NOT** hard-code node IDs.
- **MUST** browse by category, match by D-WIS names/units, and verify access modes (read/write) at startup.

Signals Units

Interface guidance for the Virtual case. Use D-WIS names; document any local mapping you implement. The issued case package will confirm applicable signals.

Category	Signal (example)	Units	Direction	Required	Notes
Actuator	Rotary speed (RPM)	rev/min	write	Yes	Top-drive setpoint
Actuator	Surface WOB setpoint	kN	write	Yes	Effective WOB at surface controller
Actuator	Flow rate (pump)	L/min	write	Yes	Flow-rate control
Actuator	Bit on/off	boolean	write	Yes	Drilling enable/disable
Measurement	Standpipe pressure (SPP)	MPa	read	Yes	Used in kick detection and dysfunction tracking
Measurement	Torque at surface	kN·m	read	Yes	Stick-slip metrics
Measurement	Hookload	kN	read	Rec.	Useful for inferred WOB and connection logic
Measurement	WOB (measured)	kN	read	Rec.	If provided by simulator/case

Category	Signal (example)	Units	Direction	Required	Notes
Measurement	Flow in	L/min	read	Yes	Flow comparison
Measurement	Flow out	L/min	read	Yes	Flow comparison
Measurement	Bit depth	m	read	Yes	Primary depth index
Measurement	Hole depth	m	read	Rec.	For drilling state and ROP reference
Measurement	ROP (surface)	m/h	read	Rec.	May be derived; include if available
Downhole	Inclination, azimuth	deg	read	If required	Survey model; station cadence per deliverables
Downhole	Toolface	deg	read	If required	If applicable to your steering model

Additions allowed

You may include additional signals (e.g., pit volume totalizer, mud density in/out, temperature) if available. Keep names/units consistent and document mappings.

Timing Sampling

- Control loop timing: choose based on your design; document nominal loop period and jitter tolerance.
- Logging cadence: record at ≥ 1 Hz for deliverables; 5–10 Hz is recommended for internal analysis where appropriate to the issued case. You may down-sample to 1 Hz for the submitted CSV.
- Time base: use UTC ISO-8601 timestamps with milliseconds (e.g., 2027-05-14T13:57:00.123Z).
- Alignment: ensure actuator writes and resulting measurements are time-aligned within your logs; document known latencies.

Data Outputs

Submit a consistent package regardless of case. Keep headers semantic and include units in parentheses for clarity.

- Submit `drilling_timeseries.csv` using the committee-issued, versioned template. Preserve its exact column names and units. Additional case-specific columns are permitted; unavailable signals must follow the template's documented missing-data rules. Submit telemetry at ≥ 1 Hz.
- Use the exact column names and units in the issued template; this section does not define an alternative CSV header.
- Document the names, units and time alignment of all additional case-specific columns, including any detection or decision flags.
- Static logs (optional but encouraged): LAS 2.0 `wellname_logs.las` for key curves and metadata.
- Plots: include time-aligned figures demonstrating objectives (e.g., flow in/out vs. SPP during connections; torque/RPM spectra for stick-slip; plan-vs-actual for directional).

Interoperability Checks

Verify OpenLab API/OPC-UA connectivity during the committee-coordinated readiness checks. All AI components must run offline during judging. See Section 4.4.

Case specific requirements

Details for the single Virtual case will be announced in the issued case package.

Formation Model Phase II

- Provided just before Phase II. Defined by rock type, unconfined compressive strength (UCS), and confining pressure.
- Prepare an importer that accepts the posted format. Your controller should account for changes in build rate due to geometry and rock strength.

Reporting Assumptions

- Survey error model: if you deviate from a standard model, include the model description, variable names, coefficients, and justification in the design report.
- Depth reference: use rotary/kelly bushing as datum unless stated otherwise; declare any alternative reference used.

Open Source OSDC

- We encourage teams to publish their work to the Open-Source Drilling Community (OSDC) as structured modules (code, data, docs). Module templates and examples will be provided.

7.3 Detailed design report requirements

- 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:
 - Who are the operators of your drilling rig and how do their characteristics impact the design?
 - Which functions of your drilling rig will be automated, and which will be manual (refer to Ref. 2)?
 - How are you going to ensure that the operator remains 'in the loop' at all times?
 - The workflow that your drilling rig will follow (very important as this will guide your interface design).
 - The control and feedback needs for your defined operators.
 - 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).

The design submittal by the students shall include:

- 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
- A description of your safety plan that is appropriate for the project
- Your process for including human factors in the design and implementation of the model.
- 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.
- 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.
- 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?
- Proposed user interface/data display that shows the progress of the model in real time.
- Cost estimate and funding plan

- Optional: a design-summary video of no more than five minutes. 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.
- Key features for any models and control software. What drilling dysfunctions are modeled and how are they mitigated?
- If you are modeling sensors, explain how specific sensors and sensor data is modeled. What did you learn from modeling sensors?
- Proposed model for data handling, i.e., inherent time delays and uncertainty.
- 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?
- 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?

7.4 Directional modeling and control

Directional modeling, steering, trajectory, target, survey, plot and directional data-log requirements in this section apply only where specified in the issued Virtual case's issued test package. Other modeling requirements apply only to the functions required by that case. The following modeling requirements apply to a team-developed virtual rig or component model. Teams using the supplied OpenLab plant must describe the plant interface, assumptions, and controller, and identify which model functions are supplied by OpenLab.

- 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.
- 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.
- 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.
- 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.
- Consider the impact of survey errors and cumulative errors for your model to make it more realistic.
- 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.
 - 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.
 - 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.
 - 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.
 - 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 Section 10.
- Additional optional items for the directional drilling option:

- If the drilled path does not intersect a target, explain the deviation from the planned virtual trajectory and assigned targets and the controller's response.
- 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.

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.

Steering

- Steering requirements (e.g. toolface direction, slide length) must be calculated autonomously
- 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.
- Orientation of steering mechanism must be calculated by the system and shown on the rig floor display.
- 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.

Surveys

- Directional surveying process must be entirely autonomous
- Survey qualification must be autonomous. Human review and modification are permitted between attempts, not during a scored autonomous run. Safety intervention ends the scored attempt.
- 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

Deliverables Requirements Magnetic surveying

- Teams whose issued Virtual case's issued test package requires directional surveying shall 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

Plots

- Teams whose issued Virtual case's issued test package requires directional deliverables shall 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

Data Logs

- Teams whose issued Virtual case's issued test package requires directional surveying shall 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

Formation Characteristics

- DSATS will furnish a formation model immediately prior to the Phase II test.
- Teams should prepare in advance to import or manually enter the data, as they prefer.
- 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 committee will issue the formation data format for 2027.

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 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).
- DSATS has provided the following bit model for the Phase II test.
 - Input:
 - Formation Aggressiveness (provided by Contest),
 - Bit Aggressiveness Factor between 0.7 and 1.3 (Contestants will select a bit with this value, which remains constant through the run.),
 - Weight-on-Bit,
 - Bit RPM,
 - Drilling efficiency provided by the contest: $\eta = 0.35$
 - Bit Diameter ("D") (provided by Contest),
 - Formation confined compressive strength ("CCS") (provided by Contest according to a formation model/prognosis),
 - 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)
 - Output:
 - Axial Rate of Penetration

- Lateral Rate of Penetration
- Bit Torque

$$\mu = a_f \times a_b$$

$$ROP = \frac{13.33 \times RPM \times \mu \times WOB \times \eta}{D \times CCS}$$

ROP is in ft/h with the field-unit inputs defined below. Derived from the Teale MSE concept (1965).

$$TOB = \frac{D \times \mu \times WOB}{36}$$

TOB is in ft·lbf. Derived from Pessier and Fear, SPE 24584 (1992).

$$ROP_{lateral} = \frac{c_s \times F_s \times RPM}{D \times CCS}$$

The lateral ROP is in ft/h. The equation symbols correspond to the code variables below: a_f formation aggressiveness; a_b bit aggressiveness factor; η drilling efficiency (Eff); c_s side-cutting factor; F_s side force.

- The following MATLAB example implements the bit-model equations. Its assignments are retained as executable code.

```
function [ROP, ROPlateral, TOB] = rop_tob_drillbotics( ...
    formation_aggressiveness, 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_aggressiveness, [ ] (drilling aggressiveness, Torque/WOB ratio
% which is heavily influenced by formation type. Based on Pessier and Fear,
% 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_aggressiveness * 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

- 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.

Drillstring

- Teams should specify the physical characteristics of the drillstring used in their analysis.
- The Drillstring may be represented by one or more models. These models will have to do the following:
- 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.

- 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.
- 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.
- Please do not attempt to model lateral vibrations of the Drillstring or 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 configurable parameters in the design.
- 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?

7.5 Virtual case implementation

Implementation details for the single Virtual case will be announced in the issued case package.

7.6 Software and operator display

Coding

- 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.
- 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.
- 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.

Data visualization

- Teams must provide a display to observe the status of the model.
- Novel ways of presenting the data and progress of drilling in real time will receive particular attention from the judges.
- 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.
- 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."

Phase I design Report

- 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.

- 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.

Human review and modification are permitted between attempts, not during a scored autonomous run. Safety intervention ends the scored attempt.

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.

7.7 Phase II testing

- During Phase II, teams demonstrate the objectives and constraints of their issued Virtual case. Directional trajectory and target requirements apply only where specified in that case's issued test package.
- 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.
- 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.
- 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.
- For virtual directional testing, the committee will provide the applicable target and case information. The Physical-only predefined trajectory in Section 5 does not apply.
- The rock properties will be provided as a function of true vertical depth or measured depth at that time.
- Drillbotics may provide data to calibrate sub-models such as the bit model. Additional details will be released during Phase II.
- **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.

The three-hour window applies to the virtual directional drilling test. Debugging and modification are permitted between attempts within that window; each scored run must execute autonomously. The issued measurement sheet will state which attempt counts and how the issued Virtual case is timed and assessed.

8 Mode Physical requirements

Physical Rig Challenge teams must supply their own rock samples for development and the competition. The organizers will not supply rock samples or introduce surprise formations.

8.1 Hardware and engineering design

- Power: provide a table of expected electrical power consumption for major devices (rotation, hoist, pump, controls, displays, etc.), including voltage, current, phase, and estimated HP/W. This supports booth planning if the rig is displayed at the Drilling Conference.
- Dimensions: provide a diagram of maximum rig dimensions when operational (including auxiliaries) to verify venue/booth fit.
- Shipping: calculate the “Chargeable Weight” including crates/boxes; include dimensional-weight calculations per common carrier rules.
- Sensors: specify surface and downhole sensor packages, verification/calibration methods (accuracy, precision, frequency response, environmental stability), and placement. Include plans for along-string sensing where applicable.
- Data acquisition: define sampling rates, synchronization across surface/downhole streams, and data handling pipelines.

Rig Design

- 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 winning team may need to ship their rig by airfreight to display it at an industry conference. Please give considerable thought to the physical design to reduce the overall dimensions. Designs with a folding and/or telescopic derrick and nested bases can reduce the shipping costs considerably. For this reason, Drillbotics asks students to calculate the “chargeable weight” as described below, and judges use this figure when comparing team performance.
- 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.
- 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.
- 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 Sections 7 and 8 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.
 - Distinguish in all data and documentation the difference between Weight-On-Bit and Hook Load; be specific when referring to these parameters.
- 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.
 - The circulation and containment design must accommodate the properties of the team-supplied sample. Teams must describe the sample composition and preparation.
 - 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.

Design Calculations

- Design submittal by the students shall include:
 - Engineering drawings of the rig concept, mechanical and electrical and auxiliary systems, if any
- Design notes and calculations

- 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 2027 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 it was chosen, what engineering assumptions were made, a definition of all variables and the values used in the calculation.

Example:

Buckling limit example using Euler's equation

The critical buckling load, P_{cr} , is calculated:

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2}$$

P_{cr} : 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)

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

Example

Parameter	Symbol	Calculated field units	Calculated SI units	Safety factor	Limit field units	Limit SI units	Reference	Notes
Critical buckling load								
Burst limit								
Torque limit								
... Other								

- Because the winning team's rig could be shipped to a different country for display in the SPE booth at the Drilling Conference, the Drillbotics team needs to prepare in advance to provide adequate electrical power for the rig. Please provide a table showing the expected power consumption. Rename devices as appropriate:

Device	Voltage	Current	HP	Watts	Single or three phase	Notes
Rotation						
Hoist						
Pump						
... Other						
Controls						
Displays						
...						
Total						

- Also provide a 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]

- Please calculate and include in your report the “Chargeable Weight” of the rig, including shipping crates/boxes for the 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.

$$m_{chargeable} = \max(m_{actual}, m_{dimensional})$$

- Package volume from dimensions in inches:

$$V_{in^3} = L \times W \times H$$

- Dimensional weight in pounds:

$$m_{lb} = \frac{V_{in^3}}{166}$$

- Dimensional weight in kilograms from inch dimensions:

$$m_{kg} = \frac{V_{in^3}}{366}$$

- Dimensional weight in kilograms from centimetre dimensions:

$$m_{kg} = \frac{L \times W \times H}{6000}$$

- Control system architecture. (The response time of measurements, data aggregation and control algorithms should be estimated.)
- Key features for any models and control software.
- Proposed data handling and display.
- 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.
- 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.
- 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.
- An explanation of the algorithm used to autonomously control the drilling rig based on the output of the BHA sensors.
- An explanation of the principles being applied to directionally steer the wellbore and hit the required targets with the intent to score the maximum amount of points.
- Cost estimate and funding plan
- Optional: a design-summary video of no more than five minutes. 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.
- All design, construction and operation of the project are subject to the terms and conditions of Section 14.
- The Committee) will review the Phase I designs and select the top-ranking teams who will progress to Phase II of the competition.

8.2 Autonomous control and surveying

- Mode switching: automate drilling/survey mode transitions (built-in survey interval; on/off-bottom; slide/rotation switching with appropriate string movement).
- Steering: compute toolface direction, slide length, and other steering requirements autonomously. Human intervention to place/retrieve mechanisms (e.g., whipstock) is allowed, but orientation must be system-computed and displayed.
- Surveying: fully autonomous surveying and autonomous survey qualification; secondary human verification/override is allowed and must be flagged.
- Monitoring: compute and display dogleg severity, and distance/direction to plan at each survey station on the rig display.

- Control architecture: document measurement/aggregation latencies and controller update rates; design for robust closed-loop control using downhole data.

Mandatory Rule

- Surveying and survey qualification are autonomous; human verification/override **MUST** be flagged.
- Control design **SHALL** support robust closed-loop operation based on downhole data.

Downhole Sensors

A scored Physical run must demonstrate closed-loop control using downhole measurements. A run that does not meet this requirement is ineligible for ranking. Sensor failure, replacement and resumption are governed by Section 8.6.

Surveys

- 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.

Deliverables Requirements Magnetic surveying

- 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
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 - 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.

Plots

- 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

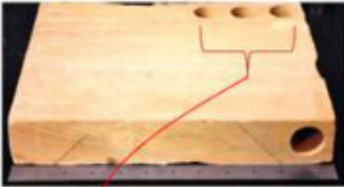
Data Logs

- 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.

8.3 Rock samples and drill bits

Formation Rock

- The university and/or students must acquire or produce, at their own cost, the rock samples used for verification, practice and the final Physical Rig Challenge. Sample composition and preparation must be documented. The organizers do not supply rock samples or undisclosed formation layers.
- For the final test, the teams will need to procure the rock and get the rock tested. A typical sample has the following properties:

Test Data			
			
Test ID#	Compressive Strength (PSI)	Young's Modulus (PSI)	Poisson's Ratio
1	2298	1.70 E+6	0.13
2	3095	1.52 E+6	0.26
3	1845	1.31 E+6	0.26
4	6230	1.72 E+6	0.20
5	4553	1.27 E+6	0.14
6	5305	1.50 E+6	0.21

Typical rock sample properties

- The sample should be prepared per the following:
 - Teams may choose the dimensions of their competition sample, with no dimension exceeding 100 cm. Sandstone is a reference material.
- Please contact Drillbotics at competition@drillbotics.com if you have difficulty obtaining your sample.

Physical teams are responsible for supplying and characterizing their own competition sample. The properties shown above are a typical reference. The committee will not introduce a surprise formation.

Planning recommendation for a future horizontal-steering trajectory. Use an elongated rock sample with sufficient usable length to contain the build, hold and azimuth-turn sections. Its height and width should accommodate the complete curved path, survey uncertainty, steering corrections and clearance for the selected bit, BHA, stabilizers and drillstring.

For preliminary layout planning, a usable length of approximately twice the usable height is recommended where practical. This proportion is advisory, not a minimum eligibility requirement or a guarantee of trajectory fit. Verify the full three-dimensional swept envelope of the tools and planned borehole; a vertical start generally needs more room to reach horizontal than an inclined start.

The committee will publish recommended minimum usable sample dimensions and required clearances with any future horizontal-steering trajectory package, together with the permitted entry face, entry point, starting orientation and curvature limits. Teams should confirm those requirements before procuring a final sample or committing to a rig layout. The existing maximum sample dimension remains in force; no new numerical trajectory or sample dimensions are prescribed here.

Bits

- Each Physical Rig Challenge team must design and supply its own drill bit for the competition. The organizers do not provide a bit. Teams must explain the bit, BHA and drillstring design, directional cutting behaviour, sensor integration and data telemetry, supported by calculations and tests.
- Teams are responsible for manufacturing or procuring the manufacture of their own bit, inspecting it and arranging any spares. No organizer-issued bit or bit-return arrangement applies.
- There are no restrictions on the size of the team-designed competition bit.
 - Teams must explain their choice of axial and lateral cutting aggressiveness and its effect on directional control, drilling performance and bit loading.
 - The design report must document the bit design, materials, cutting structure, manufacturing method, verification and test results.
- Teams must consider bit wear and cutter damage before and during the final test. Teams are responsible for their own bit and any spare components; the published test procedure will define permitted bit changes.
- Teams may build or obtain practice bits for development, but the competition bit must be their own design. Students must not receive professional assistance in designing the bit; manufacturing of the student design may be performed by a third party.
- For the 2027 Physical Rig Challenge, teams must use their own bit design. There are no restrictions on bit diameter or length.

8.4 Drillstring sensors and data

Drillstring

- Drillpipe
 - Preliminary typical tubing specifications for aluminum tubing are listed below to assist with the mechanical and electrical design of the rig. Stainless steel tubing or aluminum tubing is permitted. There is no restriction on drill pipe diameter or hole diameter; explain the selected dimensions and mechanical limits in the design report. Teams may choose durability over flexibility and shall explain their choice in the design report.
 - There is no restriction on drill pipe diameter or hole diameter.
 - DSATS will not be providing tubing to the competition teams.
 - The use of a metric equivalent of the tubing is permitted.
 - 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>

- Tool joints
 - Students may design their own tool joints as long as the design concept is included in the Phase I proposal.
 - 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.
 - A fitting used somewhat successfully in 2017 is available from Swagelock. In 2018, the winning team used a fitting from Vertex.



Example tool joint fitting

- 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.
- Students must state WHY they choose a tooljoint design in the Phase I proposal.
- Bit sub/drill collar/stabilizers
 - It is expected that each team will design and build their own bit sub. Instrumentation of the bit sub is ideal for directional sensors.
 - 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
 - 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.
 - 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.
 - 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%.

Automated Drilling

- 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.
- Once drilling of the sample commences, the machine should operate autonomously. Remote operation and manual control are prohibited except for the interventions explicitly permitted in these guidelines. Log each intervention, its reason and duration; apply the published timing and scoring rules.
- All directional control operations should be autonomously controlled by the drilling rig.
 - 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.
 - 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.
 - Directional surveys acquired by the system need to be used as feedback for the steering control (and/or calculation of the steering requirements) logic.
- 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.

Sensors

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

- The team may develop its own sensors if so desired.
- Sensor quality differs from data quality. Both are important considerations in this competition.
- The final report shall address which sensors were selected and why. The sensor calibration process shall also be explained.

Data collection and handling

- 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.
- The final report shall address which data systems were selected and why.
- 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.
- Describe how data is measured, aggregated, stored and retrieved. Describe calibration and data validation techniques used.

Data visualization

- Novel ways of presenting the data and progress of drilling in real time while drilling will receive particular attention from the judges.
- 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.
- 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.
- 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."
- An End of Well (EOW) report should be provided to the judges at the conclusion of drilling.

Measure and analyze the performance

- 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.
- Design limits of the drilling machine shall be determined and shall be incorporated in the programming of the controls during the construction phase.
- Downhole measurements from directional sensors are to be used for adjusting drilling parameters and control of drilling machines used to aid in directional drilling.

Excluded operations

- 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).
- A rig move, walking or skidding is not required, but the mobility of the rig will be considered in the design phase.

8.5 Phase I design report

The design submittal by the students shall include:

- 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.
- A description of your safety plan that is appropriate for the project.

- Engineering sketches or drawings of the rig concept, mechanical and electrical and auxiliary systems, if any, that explain your design assumptions
- Include any design notes and calculations regarding rig, drillstring and other limitations for the particular modules used in your models.
- A block diagram/flowchart of the modeled control system architecture. 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?
- Since this is a directional drilling problem, be sure to include how 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 with the intent to score the maximum number of points.
- Proposed user interface/data display that shows the drilling progress in real time.
- Cost estimate and funding plan
- Key features for any models/modules and control software. What drilling dysfunctions are addressed?
- Proposed data handling, i.e., inherent time delays and uncertainty.
- 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?

Additional optional items:

- Optional: a design-summary video of no more than five minutes. 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.
- Teams will submit a detailed report containing detailed literature review, model assumptions, overall plan of the rig and control 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 modeling and rig testing should be included, along with a discussion on the results.
- 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.
- A safety case shall be part of the Phase I design (see Section 3). 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.
- 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?
- 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.

8.6 Phase II testing

- During Phase II, qualifying teams will build the rig and use it to drill rock. Drilling a deviated well to hit at least two required targets in different vertical steering planes, including an azimuth turn (see Section 5), efficiently through the sample while controlling drilling dysfunctions is the primary technical objective of the competition. Scoring of trajectory and target accuracy follows the issued reference path and measurement sheet in Sections 5 and 11. A scored Physical run must demonstrate closed-loop control using downhole measurements. A run that does not meet this requirement is ineligible for ranking. Surface and downhole measurements must be used to control drilling in real time. A failed downhole sensor may be replaced and the run resumed within the published time limit, provided closed-loop control is restored before drilling resumes. Log the failure,

replacement and intervention duration. Sensor replacement time is included in drilling time for calculation of ROP.

- Prior to the start of the test:
 - Except for the tilted-rig configuration in Section 8.7, 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. For Section 8.7, the pilot hole follows the local reference axis defined in the trajectory package; all other pilot-hole limits apply. 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. The pilot-hole starting point will match the trajectory package issued three calendar months before the physical competition.
 - At their option, teams may use a straight housing for the pilot hole and then replace it with the bent housing for the drilling. Teams may choose the pilot-hole bit size.
 - 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.
- The committee will provide the predefined build–drop–hold trajectory to Physical teams three calendar months before the physical competition.
- Presentations
 - The contest will begin with streaming of a pre-recorded presentation by each team. This will be followed by 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.
 - 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.
 - The presentations should include the details of the rig and downhole equipment and control schemes. If the team wishes to protect confidential proprietary concepts, please contact the Committee in advance so we can prepare accordingly to shield your ideas.
- The Test
 - When the competition drilling begins, teams will be required to continue to drill the pilot hole vertically to the kickoff point, except under Section 8.7, where the initial interval follows the tilted starting direction in the defined local frame. The kick off point may be at any depth greater than 4" below the surface of the rock.
 - All rigs start the drilling competition at the same time.
 - Navigation shall be done autonomously
 - 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.
 - No lateral forces are allowed to be applied above the top face of the rock.
 - No forces are allowed to be applied external to the rock that will force the drill bit in a particular direction
 - 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
 - Once drilling commences, the test will continue until the drill bit exits the rock sample, or three (3) hours, whichever comes first
- Evaluation
 - Drilling performance will be observed and measured by Drillbotics judges invited to attend and witness the test. The committee will announce the 2027 venue and any remote participation arrangements.
 - Directional performance is assessed against the predefined build–drop–hold reference trajectory, its azimuth turn and at least two targets in different vertical steering planes, using the measurement sheet issued under Section 11.
 - With respect to well path tortuosity, judges may insert a "flexible casing" to drift the wellbore to obtain a relative measure of borehole quality.

8.7 Optional tilted rig challenge

Physical Rig Challenge teams may optionally start the well with a tilted rig to earn bonus points. Teams undertaking this challenge shall follow the same predefined trajectory and targets as the other Physical teams.

The initial drilling direction defines the local reference axis and zero local inclination. The trajectory package shall define the local azimuth reference and the transformation between local and global coordinates. Record the full starting orientation and transformation used. The issued trajectory and target positions shall be rotated into this reference frame without changing their relative geometry. The pilot hole and initial interval to the KOP follow the tilted starting direction. References to vertical, azimuth and displacement in the trajectory envelope are interpreted in this same local frame.

The challenge is optional. The committee will publish the approved bonus points, maximum award and verification criteria in a separate, versioned rubric before teams commit designs, as required by Section 11.2. All other Physical Rig Challenge requirements continue to apply.

Future horizontal-steering trajectory. A horizontal-steering or alternate-entry challenge will be defined in a separately issued, versioned trajectory package before it becomes a competition requirement. The package shall specify the reference frame, targets, permitted starting orientation and entry face, any exceptions to Section 8.6 and the applicable scoring rubric. The planning recommendations in Section 8.3 do not replace the issued reference trajectory. Tilting the existing trajectory preserves its curvature and does not establish that a vertical-to-horizontal build will fit the sample.

9 Human factors and interface design

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]:

- The computer offers no assistance, and the human must do it all
- The computer suggests alternative ways to do the task and the human selects from those suggestions and executes the task
- 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
- 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:

- 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.
- 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 Lianne 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;

• 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.

10 Technical resources and references

Resource	Location
Competition information and previous reports	https://drillbotics.com/ and https://drillbotics.com/archives/
Questions and clarifications	competition@drillbotics.com
D-WIS vocabulary	https://d-wis.org/vocabulary-index/
OpenLab simulator	https://openlab.app/
Open-Source Drilling Community	https://opensourcedrilling.org/
SPE author resources	http://spe.org/authors/resources/

- Florence, F., Losoya, E., Drillbotics with Fred Florence and Enrique Losoya (2020, August 18), SPE Podcast, Link.
- 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
- 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
- Pehlivan Türk, 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
- 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.
- 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
- 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
- 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
- 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
- Franklin, G. F., Powell, J. D., Emami-Naeini, A., & Powell, J. D. (1994). Feedback control of dynamic systems, 3rd Edition, Reading, MA: Addison-Wesley.
- Ogata, K. (2003). System dynamics, 4th Edition, Upper Saddle River, NJ: Prentice Hall.
- Ogata, K. (2009). Modern control engineering, 5th Edition, Upper Saddle River, NJ: Prentice Hall.
- Li, Y., Ang, K. H., & Chong, G. C. (2006). PID control system analysis and design. IEEE Control Systems Magazine, 26(1), 32-41.
- Rawlings, J. B. (2000). Tutorial overview of model predictive control. IEEE control systems magazine, 20(3), 38-52.
- Webinar: Machine Learning and Physics-based Solutions for Drilling Automation by SPE Distinguished Lecturer Prof. John Hedengren, Brigham Young University, YouTube Video.
- Webinar: Drilling Automation and Downhole Monitoring with Physics-based Models. Link.
- Video and Webinar Series: Understanding Control Systems by Mathworks. Link.

11 Scoring procedure

Each mode is assessed against the six categories and maxima shown on its scoring sheet. The base category score is out of 100 points. Awarded Edge-AI bonus points and, for Physical teams, optional tilted-rig bonus points are added to form the total point count. The innovation multiplier is then applied once to that total. Judges record the evidence supporting each award and provide the completed score summary to the team after judging.

For qualitative assessment, judges assign a rating from 0 to 5 using the descriptors below. Category points equal the category maximum multiplied by the rating and divided by 5. For measured performance, the published measurement sheet defines the conversion from the observed result to a rating. Category maxima remain unchanged.

$$Q_i = \frac{w_i r_i}{5}$$

Here w_i is the category maximum, r_i is the rating and Q_i is the awarded category score before the total-score innovation multiplier.

Rating	Assessment descriptor
0	No usable evidence or demonstration of the assessed requirement.
1	Limited evidence; major shortcomings prevent reliable achievement.
2	Partial achievement; significant limitations or incomplete verification.
3	The assessed requirements are met and supported by adequate evidence.
4	Strong achievement, supported by convincing verification and clear handling of relevant limitations.
5	Outstanding achievement, demonstrated consistently with comprehensive verification and well-supported engineering decisions.

Judges first assess the demonstrated outcomes and engineering quality without an innovation adjustment. Judges review the same submitted evidence and competition records, score independently, and then record the panel's agreed result and reasons. Any correction to a measurement or calculation is documented before finalization. Separate modes are ranked separately. The measurement sheet states how multiple tests or cases contribute to each category.

11.1 Innovation multiplier

An especially innovative approach may receive one innovation multiplier on the total point count, up to a maximum of 1.25. Contributions may concern mechanical design, sensing, control, safety, human factors, data handling or other relevant engineering work. The choice of a particular algorithm or model family does not itself qualify. For example, a total of 80 points before the multiplier becomes 100 points at 1.25. The increase is 20 points; the multiplier is not a flat 25-point award.

Multiplier	Evidence required
1.00	No qualifying innovation adjustment.
Above 1.00 up to 1.25	Documented innovation with comparative evidence of improved outcomes. The committee will publish the exact intermediate factors and evidence thresholds in the approved, versioned rubric before teams commit designs, as required by Section 11.2.
1.25 maximum	Especially innovative work supported by convincing, repeatable evidence of substantial benefit; the committee must publish the evidence threshold for the maximum factor before teams commit designs and identify the approved rubric in Section 11.2.

The innovation factor is applied once to the total point count and is not capped at an individual category maximum. Judges record the contribution, comparison baseline, measured benefit, limitations and reasons for the factor. Tilted-rig and Edge-AI bonuses follow their approved, versioned rubrics. Before teams commit designs, the committee will publish how the same innovation and evidence are treated

across base categories, the Edge-AI bonus and the innovation multiplier, including any exclusions or requirements for separate evidence. Section 11.2 governs the release and identification of that policy. No points are added or subtracted outside the published scoring rules.

$$S_{base} = \sum_{i=1}^6 Q_i$$

$$S_{total} = S_{base} + B_{AI} + B_{tilt}$$

$$F = M \times S_{total}, \quad 1 \leq M \leq 1.25$$

B_AI is the awarded Edge-AI bonus, up to 10 points. B_tilt is the awarded optional tilted-rig bonus for Physical teams and is zero for Virtual teams. M is the innovation factor and F is the final score. The committee will publish the approved tilted-rig bonus values, maximum award and evidence thresholds in the versioned rubric required by Section 11.2 before teams commit designs. The final score is not capped at 100 or 110 points.

11.2 Performance measurement and common test conditions

The committee will issue the authoritative measurement sheet, test packages and scoring rubrics as separate, versioned releases. Each release shall state its title, stable download link, version and release date and identify the mode, case or challenge to which it applies. These documents must be published before teams commit designs; the Physical trajectory package follows the three-calendar-month notice in Section 5.

Authoritative measurement sheet. The issued sheet shall identify the applicable Virtual case/test packages and Physical trajectory package by version. It shall define common setup and test conditions, calibration, sampling, time limits, timing boundaries, permitted interventions and measurement methods.

Attempt selection. The measurement sheet shall state the number of permitted attempts, which attempt or attempts count, the selection or aggregation method and how multiple tests or cases contribute to each category. The same published rule applies to all teams undertaking the same test.

Scoring conversions. The measurement sheet shall define measured metrics, units, reference values, tolerances and the exact conversion from each measured result to a 0-5 rating. Category points equal the category maximum multiplied by the rating and divided by 5, as specified in Section 11. Category maxima remain those in Section 4 and the scoring sheets.

Incomplete or interrupted runs. The measurement sheet shall define eligibility, treatment of missing or partial measurements, partial-credit rules and attempt-selection consequences. A Virtual safety intervention ends that scored attempt under Section 7.6. Physical sensor replacement and resumption follow Section 8.6; a run that does not demonstrate closed-loop control using downhole measurements is ineligible for ranking.

Authoritative scoring rubrics. Before teams commit designs, the committee shall publish the tilted-rig bonus point values, maximum award, verification criteria and evidence thresholds; exact innovation factors between 1.00 and 1.25 and the evidence threshold for each factor; and how the same innovation and evidence are treated across base categories, the Edge-AI bonus and the multiplier, including any exclusions or separate-evidence requirements. The Edge-AI maximum remains 10 points and the innovation maximum remains 1.25.

Release control. The committee shall publish complete measurement and scoring releases and communicate their availability and any subsequent changes to all registered teams under Section 1.1. Judges shall record the applicable package, measurement-sheet and rubric versions on the scoring sheets. Unpublished values or criteria must not be used for scoring.

12 Virtual mode scoring sheet

Team: _____ Test/case: _____

Date: _____ Judges: _____

Measurement sheet version: _____ Virtual case/target version: _____

Category	Max	Rating	Points	Evidence ref
Trajectory / Test / Target Accuracy	25	_____	_____	_____
Drilling Efficiency (Time to TD / ROP)	25	_____	_____	_____
Well-Control & Dysfunction Handling	15	_____	_____	_____
Safety & Compliance	10	_____	_____	_____
Human Factors & UI Clarity	10	_____	_____	_____
Automation Quality & Innovation	15	_____	_____	_____
Base subtotal	100	—	_____	—
Optional Edge-AI bonus	10	—	_____	_____
Total before multiplier	—	—	_____	—
Innovation multiplier	1.25 max	—	_____	_____
Final score	137.5 max	—	_____	—

Record the category rating and awarded points before any innovation adjustment. Add the applicable awarded bonuses, then apply the innovation multiplier once to the total. M is between 1.00 and 1.25.

$$F = M \times (S_{base} + B_{AI})$$

Evidence / reason	Record
Category evidence and rating	Category / rating / report page or log reference: _____ _____
Innovation adjustment	Contribution / baseline / measured benefit / total-score factor / reason: _____ _____
Optional bonus	Evidence / calculation / reason: _____
Gates	Interoperability: Pass / Fail Safety disposition: _____
Final record	Calculation checked by: _____ Panel sign-off: _____

13 Physical mode scoring sheet

Team: _____ Test: _____
 Date: _____ Judges: _____
 Measurement sheet version: _____ Trajectory version: _____

Category	Max	Rating	Points	Evidence ref
Trajectory / Path Quality / Tortuosity	20	_____	_____	_____
Drilling Efficiency (Time to TD / ROP)	20	_____	_____	_____
Safety & Procedure Compliance (E-Stop, Guards, Limits)	20	_____	_____	_____
Data Quality: required CSV, calibration, sampling rate and semantic metadata; LAS assessed only if submitted.	10	_____	_____	_____
Human Factors & UI Clarity	10	_____	_____	_____
Design & Automation Quality	20	_____	_____	_____
Base subtotal	100	—	_____	—
Optional Edge-AI bonus	10	—	_____	_____
Optional tilted-rig bonus	Rubric	—	_____	_____
Total before multiplier	—	—	_____	—
Innovation multiplier	1.25 max	—	_____	_____
Final score	—	—	_____	—

Record the category rating and awarded points before any innovation adjustment. Add the applicable awarded bonuses, then apply the innovation multiplier once to the total. M is between 1.00 and 1.25.

$$F = M \times (S_{base} + B_{AI} + B_{tilt})$$

Evidence / reason	Record
Category evidence and rating	Category / rating / report page or log reference: _____ _____
Innovation adjustment	Contribution / baseline / measured benefit / total-score factor / reason: _____ _____
Bonus points	Edge-AI and tilted-rig bonus evidence / calculation / rubric reference: _____
Gates	Interoperability: Pass / Fail Safety disposition: _____ Downhole measurements used in closed-loop control: Pass / Fail. A scored Physical run must demonstrate closed-loop control using downhole measurements. A run that does not meet this requirement is ineligible for ranking.
Final record	Calculation checked by: _____ Panel sign-off: _____

14 Terms recognition and use of the Drillbotics name

14.1 Prizes and recognition

The prize structure for the current cycle is being actively reworked and improved. In addition to the SPE/IADC paper publication opportunity, we plan to include additional forms of recognition, contingent on available budget. More updates to come.

The committee will confirm the 2027 awards, publication invitations, exhibition opportunities, and any travel support. Travel grants, if awarded, remain subject to available funding and prior approval of covered expenses. The established limit is five students and one supervisor per team, including a team formed by two universities.

Where support is approved, the committee will specify covered economy travel, local transport, accommodation, per diem, and registration costs. Reimbursement requires the approved expense statement and receipts. Teams must not make commitments on the assumption that an award or reimbursement is guaranteed.

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.

DSATS may provide additional awards, at its sole discretion.

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

14.2 Terms and conditions

- 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.
- By entering this competition,
 - 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.
 - 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 the numbered, dated clarifications issued under Section 1.1.
 - Winning teams and finalists must agree to the publication of their names, photographs and final paper on the DSATS web site.
- 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.
- 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.
- Participants must comply with all local laws applicable to this contest.

14.3 Marketing and trademark

- Upon request, DSATS will provide a link on its website to all participating universities.
- If university policy allows, various industry journals may send a reporter to witness the tests and interview students to publicize the project.
- 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.
- 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.