## 1 | Use Case Title: Machine Teaching for Tunnel Boring Machines

## 2 | Use Case Overview *(<=100 words) Provide a brief description of the use case and the system that your autonomous AI will improve.*

Excavation by Tunnel Boring Machines (TBM) poses technical difficulties in terrains with high clay content due to formation of mud cake in the cutterhead. This can result in soil disturbance of the tunnel face, clogging and possible damage of cutterhead, and affect the efficiency of the excavation.

There are several indicators that can lead the operator to suspect the formation of mud cake, such as: temperature reading in cutterhead, knowledge of terrain, rotation and propulsion of TBM.

## 3 | Use Case Value *(<=100 words) Explain the value of improving the performance of this system.*

It is desirable to identify early on the possibility of mud cake formation in the cutterhead.

1. Preventive action can be done to avoid the mud cake formation (use of chemicals, adjustment of excavation operations)

2. Increased efficiency due to reduced excavation downtime associated with mudcake formation incidents.

3. Increased safety due to reduced operators’ interventions at the site.

## 4 | Current Methods *Select and explain the current methods used to control or optimize the system*

|  |  |  |
| --- | --- | --- |
|  | **Method** Check all that apply | **Description** |
|  | Human Operator / Engineer | Obtains cues from TBM sensor readings. |
|  | Expert System | Adjusts the propulsion and rotation according to sensors. |
|  | Control Theory (PID, MPC) |  |
|  | Optimization Techniques |  |
|  | Other |  |

## 5 | Limitations of current methods *Select and explain the limitations of current methods*

|  | **Limitation**  Check all that apply | **Description** |
| --- | --- | --- |
|  | Ability to control well across scenarios / conditions | Current methods rely on operator intuition of the terrain based on TBM readings, knowledge of the geology, previous experience. |
|  | Multiple or changing optimization goals | While it is of interest to avoid mud cake formation in the cutterhead, it is also of interest to balance this against equipment maintenance, cost of chemicals, efficiency in excavation progress, risk to excavation in uncertain terrain conditions. |
|  | Human Operator /  Engineer Limitations  May include  · Difficulty managing many variables and dimensions  · Difficulty adapting to changing conditions  · Large performance discrepancy between novice and expert operators  · Inconsistency across expert operators | Each TBM, terrain and operator is different, so current methods do not scale well to across multiple scenarios.  The human operator will have been trained on a certain geology, type of excavation, using a type of TBM, to acquire cues as to the best operating practices.  A novice operator does not have this knowledge built from years of experience. |
|  | Uncertainty in the measurement of the inputs or the process make it difficult to control or optimize. | The underground terrain is uncertain and can only be estimated through the use of sensors and partially, through the TBM operation (thrust and rotation of machine). |
|  | Time to develop control or optimization system is prohibitive | There are too many variables, of varying accuracy, for too many kinds of excavation conditions to be able to develop a control system. |

**Milestone 1 – Ends Here**

## 6 | Autonomous AI Overview *(<=100 words) Provide a brief description of how your proposed autonomous AI would improve the process.*

The autonomous AI would be able to identify early on the risk of mud cake formation and adjust the TBM operation accordingly, either by:

- Adjusting the TBM propulsion/rotation

- Adjusting the chemicals used

## 7 | Optimization Goal *List and describe the key performance indicators that will define control/optimization of the system Example: maximize (throughput)*

Maximize excavation (meters/day) rate.

Minimize the number of excavation interruptions.

Minimize the number of excavation interruptions requiring manual intervention at site.

Maximize equipment availability.

## 8 | Autonomous AI Components *Select and explain the automation methods your AI will use.*

|  | **Method**  Check all that apply | **Description** |
| --- | --- | --- |
|  | Math (control systems) |  |
|  | Menus (optimization) |  |
|  | Manuals  (expert rules and systems) | Some of the operations are well defined by expert rules and systems. For example:   * The temperature at the cutterhead varies when mudcake formation is created by well-understood physical principles.   The torque at the cutterhead can help identify anomalies in the excavation. |
|  | Machine learning |  |
|  | Deep reinforcement learning | Large amounts of historical data can be used to create convolutional neural networks to be continuously retrained depending on the TBM prediction. |

## 9 | Control Actions *Select and explain the level of the control actions that the brain will output to control or optimize your system*

|  | **Level**  Check all that apply | **Number of Actions** | **Description** |
| --- | --- | --- | --- |
|  | Supervisory | 3 | The brain will provide supervisory set points. |
|  | Low Level |  | Low-level control will remain with the APC controllers. |

***Select and explain the type of control actions that the brain will output to control or optimize your system***

| **Name** | **Data Type** | **Units** | **Control Frequency** | **Operating range [min, max]** | **Description** |
| --- | --- | --- | --- | --- | --- |
| cutter head rotation speed |  | Rpm | Every minute | [0, 100] with steps of 5 | The speed at which the cutter head rotates. |
| Propelling cylinders thrust |  | N | Every minute | [0, 100] with steps of 5 | The thrust exerted by the propelling cylinders into the excavation face. |
| cutter head rotation torque |  | Nm | Every minute | [0, 100] with steps of 5 | The torque of the rotating cylinders into the excavation face. |

**Milestone 2 (and 3) – Ends Here**

## 10 | Constraints *List and describe what constraints are placed on the control actions by the system or the process Example: Maximum crusher gap changed allowed per hour is 15 mm.*

The cutter head rotation speed limit is set by machine specifications.

The propelling cylinders thrust limits are set by: 1. cylinder specification limits; 2. Desired thrust into soil excavation depending on soil condition; 3. Speed at which the thrust boring machine advances.

The cutter head rotational torque is as per manufacturers specifications.

## 11 | Environment States / Sensors *List and describe what information do we need to pass to the BRAIN about the system and its environment for the BRAIN to learn to control or optimize the system*

| **Name** | **Data Type** | **Source** | **Units** | **Measurement Frequency** | **Operating Range [min, max]** | **Description** |
| --- | --- | --- | --- | --- | --- | --- |
| Cutter head rotational speed | Numerical | Cutter head Machine | Rpm | Every minute | TBC with SME |  |
| Propelling cylinders thrust | Numerical | Machine | N | Every minute | TBC with SME |  |
| Cutter head rotation torque | Numerical | Machine | Nm | Every minute | 0 – 100rpm |  |
| Soil temperature | Numerical | Thermometers around machine | Celsius | Every minute | -20 to 40C |  |
| Chemical injection rate | numerical | Auxiliary chemical injection equipment | Liters/hour | Every minute | 0 – 1l/min |  |
| Rotation direction | Categorical | Sensors in cutter head | Binary | Every minute | Clockwise/anti-clockwise |  |
| Excavation speed | numerical | GPS | Meters/hr | Every minute | 0 to 10mtrs/hr |  |

**Milestone 4 – Ends Here**

## 12 | Goals *List and describe what Key Performance Indicators (KPI) define the control or optimization of this system*

| **Goal (KPI)** | **Units** | **Description** |
| --- | --- | --- |
|  |  |  |
|  |  |  |

## 13 | Scenarios *List and describe what we need to vary in the training to ensure that the brain works well across scenarios*

| **Configuration Variable** | **Range**  **[min, max]** | **Description** |
| --- | --- | --- |
|  |  |  |
|  |  |  |

## 14 | Training Episode Length *Describe the training episode length for your use case. An episode represents the number of control actions that comprise a scenario Example: in an HVAC scenario control actions for an air conditioning unit might be taken 4 times per hour, but multiple hours need to be considered to see a diverse range of building occupancy and the temperature variation during the day. If the training episode is one day, there are 24 x 4 control actions per training episode.*

## 15 | Benchmark Episode Length *Sometimes, the benchmark scenario needs to be longer than the training scenario in order to capture the full range of variation of the configuration variables. To extend the example above, benchmarking an HVAC system requires extending the prediction scenario for a trained BRAIN to include seasonality across months. In this case, the benchmark episode length may be 1 year (356 x 24 x 4 control actions).*

**Milestone 5 – Ends Here**

## 16 | Skills / Strategies *Use subject matter expertise to identify the strategies to include in your brain design to control or optimize your system*

| **When the [environment variable list] trend in this direction or interact in this way…** | **This is what we think it means** | **This is what you should do (to manipulate control actions)** |
| --- | --- | --- |
|  |  |  |
|  |  |  |

## 17 | Other Skills / Concepts *Select and explain all type of skill or concepts in which you will decompose your brain design to control or optimize your system*

|  | **Type of skill or concept**  Check all that apply | **Description** |
| --- | --- | --- |
|  | Controllers (Open loop, FF, MPC, etc.) |  |
|  | Optimization algorithms |  |
|  | Strategy or Function |  |
|  | Selector |  |
|  | Advance perception, classification or prediction |  |
|  | Expert Rules / Constraints |  |

**Milestone 6 – Ends Here**

## 18 | Orchestration (Whiteboarding your brain design) *Organize the strategies, skills, and concepts identified in sections 16 & 17 into a whiteboard diagram using: shapes, lines, labels, and colors.*

Three Steps of Orchestration

1. Decompose your task into skills
2. Arrange how your skills work together
3. Choose a technology to perform each skill  
   *(Remember choosing the technology should be the last thing you do.)*

Copy & paste your brain design diagram, either from another application, or even as a photo of a hand drawn diagram. Be sure you include the following items:

* Shapes – follow established conventions taught in this course.
* Labels on shapes are descriptive of the strategies, skills or concepts.
* Color legend to identify the required technologies.