# Milestone 1 - Identify a Problem to Solve

Milestone 1 is where you begin working on your course project, a proposal for your own autonomous AI. Your goal is to: propose a use case, describe the value of the problem, and analyze the current system and its limitations.

You may use one of the case studies presented in the course as examples, but we strongly encourage you to be innovative and curious enough to create your own.

## 1 | Use Case Title: AAI-Controlled “Virtual Anesthesiologist”

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

An Autonomous AI-controlled “Virtual Anesthesiologist” is proposed. More specifically, an Autonomous AI-controlled *pharmacological robot* is envisioned.

The AAI “brain” would be integrated between the sensor feedback coming from The Patient (as well as a database record of additional metadata known about The Patient) and the programmatically/electronically-controlled drug titration mechanisms commonly in use in most hospital operating theatres.

This robot would provide improved (quicker response times) individualized anesthetic drug titration for optimal homeostasis during general anesthesia and sedation. This represents an improvement over current state-of-the-art systems employing various forms of closed-loop automated control.

This robot would also fill a much-needed void, as currently the Healthcare field has a severe shortage of costly, skilled human Anesthesiologists.

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

In the USA over 60,000 surgeries are performed with anesthesia daily and is increasing rapidly.

If an “average” cost of surgery requiring general anesthesia is $250,000 (a conservative estimate), this represents $15 Billion in medical costs annually.

There are currently only approximately 30,000 Anesthesiologists in the USA. This means on average any given Anesthesiologist is performing 2 surgeries per day… 7-days-a-week.

A single human Anesthesiologist’s salary is $300,000 to $600,000. This represents an average annual cost for human Anesthesiologists of (say) ($450,000 x 30,000) = $13.5 Billion annually

Currently the pace at which new Anesthesiologists are graduating from medical schools isn’t keeping up with the current demand; this situation will only get worse as this demand increases.

If even 1-in-4 surgeries could be performed by an AAI-powered Virtual Anesthesiologist, it could represent a savings of $3.3 Billion annually, while “giving back” 2 days a week to human Anesthesiologists.

## 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 | Currently only human anesthesiologists perform this activity.  The Anesthesiologist visually monitors multiple gauges (eg Blood Pressure, Respiration Rate, Blood-Oxygen Level, etc) connected to sensors attached to The Patient.  The Anesthesiologist also has some additional “profile” knowledge of The Patient (eg Age, Gender, Height, Weight, Health History, Ethnicity, General Health, Drug Allergies, etc).  Using knowledge of both The Patient Profile and The Patient Current State, The Anesthesiologist manually manipulates the controls which titrate (via breathing & via IV) a specific concentration of general anesthesia into both The Patient’s airway and bloodstream in order to achieve and maintain a specific level of unconsciousness and analgesia - the inability to feel painful stimuli (eg prick of a needle injection, cutting with a scalpel, etc).  The Anesthesiologist uses subjective manual (non-mechanical) methods (The “Glasgow Coma” Scale) to assess (not “measure” per se) The Patient’s Level of Consciousness, and arrive at a numerical “score” between 3 (coma or brain-dead state) to 15 (fully-awake patient). Achieving a GCS score of 9 to 12 is a commonly-accepted criteria for surgery to commence.  General Anesthesia only work temporarily; that is – it “wears off”. As such, during The Operation The Anesthesiologist continues to monitor The Patient’s “vitals” for indications of returning-to-consciousness or reaction to painful stimuli, and makes adjustments to Anesthesia titration levels as needed. This is a non-trivial “control process”, one which requires literally years of practice to perform. |
|  | Expert System |  |
|  | Control Theory (PID, MPC) | Some (limited and still experimental) used of various closed-loop PID feedback control have been tried, but with limited success. None of these current methods can simulate the expert decision-making human Anesthesiologist provide. |
|  | 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 automation based on closed-loop feedback control assumes a “typical” patient, disallowing any customization of drug titration specific to a particular patient. Drug Titration adjustments based on patient age, gender, size, body mass, ethnicity, and general health are currently not possible. |
|  | Multiple or changing optimization goals | Different patients respond to drug titration differently. No single optimization strategy fits all patients, Patient age, gender, size, body mass, general health, ethnicity and even emotional state and tolerance to pain, even type of surgery all influence “optimal” drug titration for each patient. |
|  | 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 | The ability for a human Anesthesiologist to decide on an optimal “customized” Drug Titration Plan for a given patient – and to be able to adjust that plan even during surgery – depends almost entirely on the education, training, experience and practical skill of the Anesthesiologist.  While performing “typical” surgeries with no unusual risk factors and no unusual events occurring, this may suffice. But for unusual high-risk patients, and when unexpected events do occur, the life of the patient is literally in the hands of a single individual, whose ability to keep the patient alive is based solely on his or her individual skill. Period. |
|  | Uncertainty in the measurement of the inputs or the process make it difficult to control or optimize. | This is a challenging aspect of Anesthesia, as the Level of Consciousness cannot current be quantifiably measured by a sensor, but instead must be assessed by a human using a subjective method named the Glasgow Coma Scale; and by assessing The Patient across (typically) 3 main categories (eye-opening, motor responses, verbal responses) a single-digit “score” from 3 (coma/brain-death) to 15 (fully-awake & alert patient) is determined.  On top of this a GCS score of 9 to 12 is considered an “acceptable” state of Unconsciousness for surgery to commence, but a score of 8 is indicative of head injury.  This means that even a mis-reading a single subjective test by even 1 “point” could potentially send a patient with a head injury off to surgery.  This uncertainty in determine Level Of Consciousness is a key challenge for human Anesthesiologists, and will be among the challenges to address even with an AAI Anesthesiologist. |
|  | Time to develop control or optimization system is prohibitive | Years (even decades) of manual compiling of operation logs (description, transcripts, results) would be required to even begin assembling a truly comprehensive set of rules for expert system, much less a mathematical model detailed enough to be used to control drug titration for any patient. |

**Milestone 1 – Ends Here**

The remainder of this worksheet (Part 2) can be completed after you have finished the “Learning the Solution” module (which includes course items 3.1 to 3.4).

# Milestone 2 - Identify Autonomous AI Components to Use

For this week’s milestone, we will continue working on the proposal for an autonomous AI that you began last week. This week, you will propose an autonomous AI solution, determine which of the components you’ve learned about the system will include, and explain the autonomous AI superpowers that your autonomous AI brain will exhibit.

*You may want to update Sections 1 & 2 with any new insights you’ve gained.*

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

An AAI Anesthesiologist would make human-like decisions and take human-like actions that would be based on *myriad* (simulated) “experiences”. This is an improvement over a human using only a handful of actual experiences a single human Anesthesiologist might have in a career.

An AAI Anesthesiologist would possess ML model-based “advanced” perceptions akin to “intuition” not available to an (inexperienced) human Anesthesiologist. An AAI Anesthesiologist would be able to detect patterns in these advanced perceptions and be able to decide & act up on them. This is an improvement over human Anesthesiologists who don’t have these advanced perceptions, or the ability to perceive such patterns.

An AAI Anesthesiologist would log its actions and outcomes of those actions. These would serve as new “lessons” that it would learn from every day. This is an improvement over a human Anesthesiologist who only can learn from their (limited) individual experiences.

The DRL part of the AAI Anesthesiologist brain would learn strategy & be able to adapt (handle “reasonably”) to even new situations because it would have trained on so many simulated situations that it would be able to interpolate (best) or extrapolate (ok) from its known (experienced) situations to even unknown situations. This is an improvement over a human Anesthesiologist who can only learn from their own individual experiences or a very limited number of experiences of other human Anesthesiologists.

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

This is a TRICKY question for THIS sort of application of AAI, as “optimization” tends to apply a PROCESS, and it’s challenging to cast a “surgery” and more specifically “anesthesia” as such PROCESS…

The GOAL if THIS AAI is to simply ENTIRELY REPLACE a HUMAN Anesthesiologist, and what a human Anesthesiologist DOES, and a human Anesthesiologist ISN’T trying to “optimize” anything – they’re simply KEEPING THE PATIENT FROM DYING, FROM WAKING UP, and FROM FEELING PAIN. A HUMAN Anesthesiologist ISN’T seeking to “optimize” ANYTHING, but here goes…

The textbook “goal” of general anesthesia is defined as “rendering & maintaining a patient unconscious and unable to feel painful stimuli (analgesia) while achieving homeostasis - stabilizing autonomic reflexes.” Several Critical KPIs like LevelOfConsciousness and LevelOfAnalgesia simply don’t have “direct” metrics wherein they can be measured; instead they must be “inferred” using multiple “direct” (measurable) KPIs. This is an excellent opportunity for ML-based “Advanced Perceptions” to be employed to determine these metrics.

Given the above “Process” some of the Optimization Goals could be as follows:

CONTRIVE a new KPI “TimeToAchieveTargetConsciousness” measured in seconds (eg 35 secs)

CONTRIVE a new KPI “TimeToAchieveTargetAnalgesia” measured in seconds (eg 70 secs)

CONTRIVE a new KPI “TimeToAchieveHomeostasis” measured in seconds (eg 30 secs)

OPTIMIZATION GOALS then become something like

MINIMIZE TimeToAchieveTargetConsciousness

MINIMIZE TimeToAchieveTargetConsciousness

MINIMIZE TimeToAchieveHomeostasis

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

|  | **Method**  Check all that apply | **Description** |
| --- | --- | --- |
|  | Math (control systems) | Any PID or other Control System currently used by the Anesthesia Machine will still be employed for low-level control of Drug Titrations |
|  | Menus (optimization) | This might come into play as part of the planning of initial drug titration doses for a given patient? |
|  | Manuals  (expert rules and systems) | It is expected that a set of rules already exists or will be captured & encoded from human anesthesiologists |
|  | Machine learning | MULTIPLE opportunities here for ML-based ADVANCED PERCEPTION to REPLACE what is currently a human-manual “assessment” of 3 key patient metrics:  ML MODEL for measuring/quantifying PUPILARY RESPONSE ML MODEL for measuring/quantifying MOTOR RESPONSE  ML MODEL for measuring/quantifying VERBAL RESPONSE  ML MODEL for determining LevelOfConsciousness  ML MODEL for determining LevelOfAnalgesia  ML MODEL for determining LevelOfHomeoStasis  ML MODEL for determining TargetLevelOfConsiousness  ML MODEL for determining TargetLevelOfAnalgesia  ML MODEL for determining TargetLevelOfHomeoStasis |
|  | Deep reinforcement learning | ASSUMING the existence of completely new “advanced perceptions” (via ML models described earlier in worksheet), the actual CONTROL required starts to SIMPLIFY.  The following DRL models for controlling are expected:  STRATEGY FOR: MAINTAINING Patient LevelOfConsciousness  IF/WHEN LevelOfConsciousness increases  THE­N increase Anesthesia until LevelOfConsciousness drops to TargetValue  STRATEGY FOR: MAINTAINING Patient LevelOfAnalgesia  IF/WHEN LevelOfAnalgesia decreases  THE­N increase Anesthesia/Analgesic until LevelOfAnalgesia increases to TargetValue  STRATEGY FOR: MAINTAINING Patient in Homeostasis  IF/WHEN LevelOfHomeoStasis decreases below TargetValue  THE­N increase (Respirator settings) AND decrease Anesthesia and Analgesic UNTIL LevelOfHomeoStasis returns to TargetValue |

## 9 | Autonomous AI Superpowers *Select the superpowers that your autonomous AI brain will exhibit and explain how they will lead to an improvement in the process.*

|  | **Superpower**  Check all that apply | **Description** |
| --- | --- | --- |
|  | Makes human-like decisions | The AAI Brain will be able to emulate human-like “advanced perception” taking multiple directly-measure KPIs like Pupilary Response, Motor Response and Verbal Response, and from them determine a new advanced KPI “LevelOfConsciousness”  The AAI Brain will be able to emulate human-like “advanced perception” taking multiple directly-measure KPIs like HeartRate, RespirationRate, BloodPressure, Temperature and others and from them determine a new advanced KPI “LevelOfAnalgesia” (level of insensitivity-to-pain)  The AAI Brain will be able to emulate human-like “advanced perception” taking multiple directly-measure KPIs like HeartRate, RespirationRate, BloodPressure, Temperature and others and from them determine a new advanced KPI “LevelOfHomeostasis” (operation of autonomous functions)  The AAI Brain will be able to emulate the human-like “advanced perception” taking multiple directly-measured KPIs like SurgeryType, SurgeryComplexity, SurgeryDuration, Patient Age, Gender, Ethnicity, Height, Weight, Blood Pressure, Strength, HeartRate and other variables, and from these determine appropriate “TargetLevels” of Consciousness, Analgesia and Homeostasis.  The AAI Brain will be able to emulate the human-like decisions to control the amounts of anesthesia and analgesic(s) in order to achieve “TargetLevels” of Consciousness, Analgesia and Homeostasis. |
|  | Perceives, then acts | The AAI Brain will be able to use its (never-before-tried) advanced perceptions of LevelOfConsciousness, LevelOfAnalgesic and LevelOfHomeostasis, compare this to the (pre-determined) TargetLevels, and then make the appropriate adjustments to return to TargetLevels. |
|  | Learns and adapts | The AAI Brain would be continuously logging actions, timing and results, which could then be used (even together with other AAI Brains also performing all-day-every-day) as additional training sets for continuous re-training (and hopefully improvement) |
|  | Spots patterns | NOT SURE about this. |
|  | Infers from experience | The AAI Brain would indeed “infer” (“predict”) both advanced perceptions like LevelOfConsciousness etc and responses. |
|  | Improvises and strategizes | The AAI Brain would be capable of improvising and strategizing by implementing the previously-mentioned strategies, and then potentially (as needed) selecting combinations of strategies not actually occurring in any training to “improvise” and adapt to new situations. |

## 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 | 10 | The AAI brain will decide/provide low-level supervisory set points for the existing Anesthesia Machine controllers. While there are only 5 (could go up to 9) actual “flow rates” being controlled by a human anesthesiologist, in fact the “line pressure” corresponding to each flow rate also must be controlled/maintained within a specific “working range” as well, in order to ensure the required range of flow rate is achievable.  NOTE: this could go up to 18, including Halothane(2 set points) Desflurane(2 set points), Isoflurane(2 set points) and Sevoflurane(2 set points) in addition to Nitrous Oxide. |
|  | Low-Level |  | Low-level control will remain with existing Anesthesia Machine controllers OR (only older equipment) will still be MANUALLY-SET knobs & dials.  NOTE: this is what makes an AAI-powered Anesthesiologist capable of RECOMMENDING instead of CONTROLLING an IDEAL application of AAI – many anesthesia machines absolutely REQUIRE human control, but the BIG QUESTION is WHAT SHOULD these dials & knobs be SET TO when there are SO MANY of them, and the decision-making is SO COMPLEX ! |

***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** |
| --- | --- | --- | --- | --- | --- |
| Oxygen (O2) Line Pressure | integer | psi | 10 sec | [10-58] | The O2 Line Pressure feeds the O2 Flow Rate entering the respirator attached to The Patient; below 10psi the breathing mixture becomes hypoxic (deadly) to The Patient |
| Oxygen (O2) Flow Rate | integer | lpm | 10 sec | [1-10] | The O2 Flow Rate determines the concentration of O2 in the Medical Gas mixture being delivered to the airway of The Patient |
| Nitrous Oxide (N2O) Line Pressure | integer | psi | 10 sec | [0-50] | The N2O Line Pressure feeds the N2O Flow Rate entering the respirator attached to The Patient |
| Nitrous Oxide (N2O) Flow Rate | integer | lpm | 10 sec | [1-10] | The N2O Flow Rate determines the concentration of N2O in the Medical Gas mixture being delivered to the airway of The Patient |
| Medical Air Line Pressure | integer | psi | 10 sec | [0-50] | The Medical Air Line Pressure feeds the Medical Air Flow Rate entering the respirator attached to The Patient |
| Medical Air Flow Rate | integer | lpm | 10 sec | [1-10] | The Medical Air Flow Rate determines the concentration of Air in the Medical Gas mixture being delivered to the airway of The Patient |
| Heliox  Line Pressure | integer | psi | 10 sec | [0-50] | The Heliox Line Pressure feeds the Heliox Flow Rate entering the respirator attached to The Patient |
| Heliox  Flow Rate | integer | lpm | 10 sec | [1-10] | The Heliox Flow Rate determines the concentration of Heliox in the Medical Gas mixture being delivered to the airway of The Patient |
| Xenon  Line Pressure | integer | psi | 10 sec | [0-50] | The Xenon Line Pressure feeds the Xenon Flow Rate entering the respirator attached to The Patient |
| Xenon  Flow Rate | integer | lpm | 10 sec | [1-10] | The Xenon Flow Rate determines the concentration of Xenon in the Medical Gas mixture being delivered to the airway of The Patient |

**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.*

NOTE: there are NUMEROUS manufacturers of Anesthesia Machines, so these values VARY from manufacturer to manufacturer. The values provided below come from the Owner’s Manuals from multiple popular Anesthesia Machines.

COMMON CONTROL CONSTRAINTS (across all anesthesia machine brands)  
O2 Flow Rate Control Range: 0.0 to 10.0 lpm

N2O Flow Rate Control Range: 0.0 to 10.0 lpm

Air Flow Rate Control Range: 0.0 to 10.0 lpm

OTHER (LESS) COMMON CONTROL CONSTRAINTS (not available on all anesthesia machine brands)

Agent (anesthetic mixed with N2O) Delivery Range: 0.5% to 4.0 % (concentration by volume)

Max O2 Concentration: 95%

High O2 Concentration Alarm (digital, manually set): 0% to 99%

Low O2 Concentration Alarm (digital, manually set): 0% to 99%

Hypoxic Shut-off: a solenoid automatically shuts off N2O delivery if O2 level falls below 25%

REFERENCES:

[Gradian Health UAM User Guide](https://www.gradianhealth.org/wp-content/uploads/2016/08/UAM-User-Guide.pdf)  
  
[Drager Narkomed Anesthesia System Operator Instruction Manual](https://bmet.ewh.org/bitstream/handle/20.500.12091/2138/Drager%20Narkomed%20MRI-2%20Anesthesia%20System%20Operator%27s%20Instruction%20Manual.pdf?sequence=1&isAllowed=y)

## 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** |
| --- | --- | --- | --- | --- | --- | --- |
| Patient Age | integer | patient | yrs | once | [1..120] | measureable |
| Patient Gender | categorical | patient | M/F | once | [M, F] | measureable |
| Patient Weight | integer | patient | lbs | once | [10..600] | measureable |
| Patient Body Temperature | float | sensor | degF | every 10s | [70..110] | measureable |
| Patient Blood Pressure | integer | sensor | mmHg | every 10s | [20..200] | measureable integer pair (eg 120,80) |
| Patient Pulse Rate | integer | sensor | bpm | every 10s | [0..150] | measureable |
| Patient Pulse Strength | categorical | observed | range | every 10s | [strong, normal, weak] | historically subjective |
| Patient Respiration Rate | integer | sensor | cpm | every 60s | [10-100] | measureable |
| Patient Blood O2 Concentration | float | sensor | % | every 60s | [80..100] | measureable |
| Patient Pupilary Response | integer | observed | N/A | once | [1..5] | historically subjective\*\* |
| Patient Motor Response | integer | observed | N/A | once | [1..5] | historically subjective\*\* |
| Patient Verbal Response | integer | observed | N/A | once | [1..5] | historically subjective\*\* |
| Patient Consciousness | integer | observed | N/A | every 10s | [1..5] | historically subjective\*\* |

\*\* Overall Patient “Consciousness” is currently determined subjectively using the Glasgow Coma Scale (GCS); each of 3 “responses” is assessed by a medical professional and scored (again, subjectively) on a scale of 1 (low response) to 5 (high response). A composite score of 3 signifies deep coma and/or brain death; a composite score of 15 indicates full consciousness; a score 9 to 12 is commonly sufficiently “unconscious and unresponsive to pain” for most surgeries.

**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.