

Verification and Validation Report: CVT Simulator

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1 Revision History

| Date | Version | Notes |
|--------|---------|-------|
| Date 1 | 1.0 | Notes |
| Date 2 | 1.1 | Notes |

2 Symbols, Abbreviations and Acronyms

| symbol | description |
|--------|-------------|
| T | Test |

[symbols, abbreviations or acronyms – you can reference the SRS tables if needed —SS]

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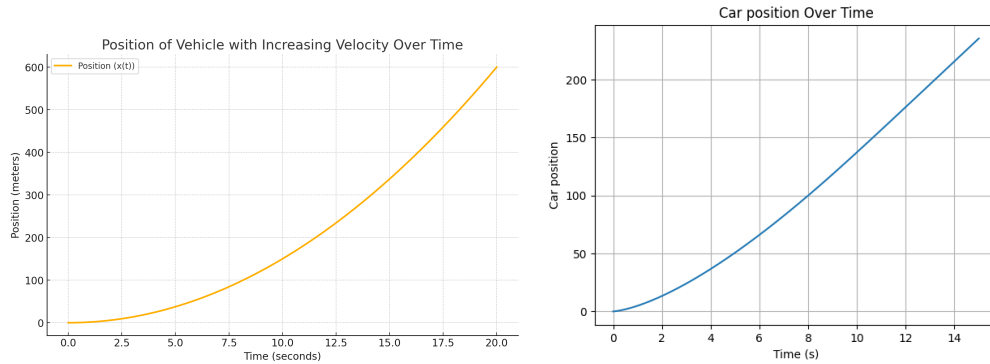
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3 Functional Requirements Evaluation

3.1 Simulation Model

3.1.1 Position

1. Position test-1: Graphical validation

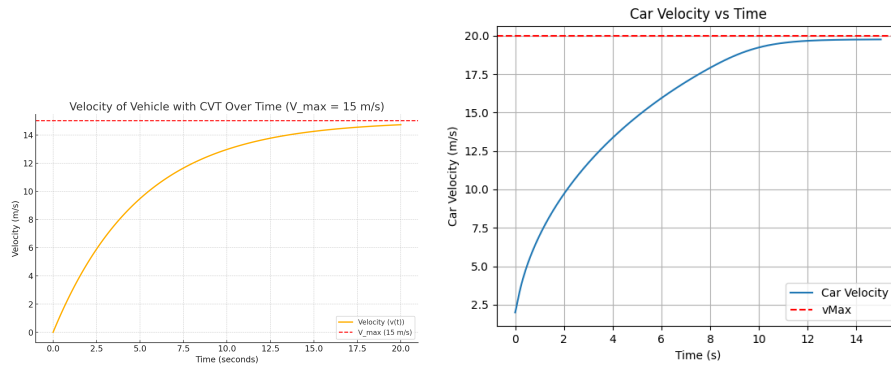


As seen above, the simulation output for the position of the car is consistent with the theoretical model. The larger initial slope can be attributed to an initial velocity, which is required due to Assumption of no slip [REFERENCE HERE].

2. Position test-2: MSE against experimental data (SEE VNV EXTRA)

3.1.2 Velocity

1. Velocity test-1: Graphical validation

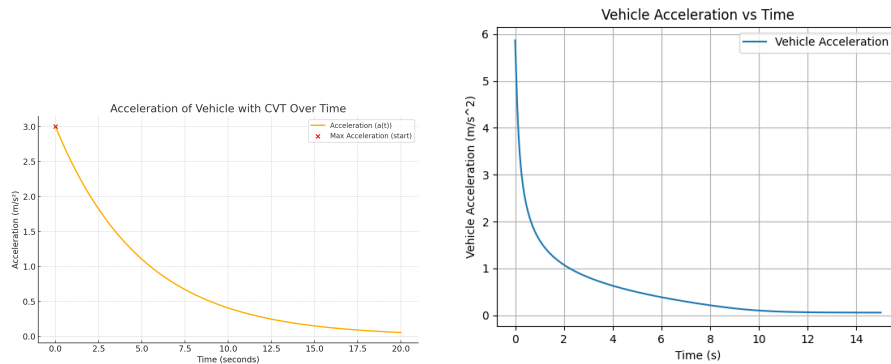


As seen above, the simulation output for the velocity of the car is consistent with the theoretical model. The v_{\max} may be subject to changes according to approximations when calculating air resistance.

2. Velocity test-2: MSE against experimental data (SEE VNV EXTRA)

3.1.3 Acceleration

1. Acceleration test-1: Graphical validation

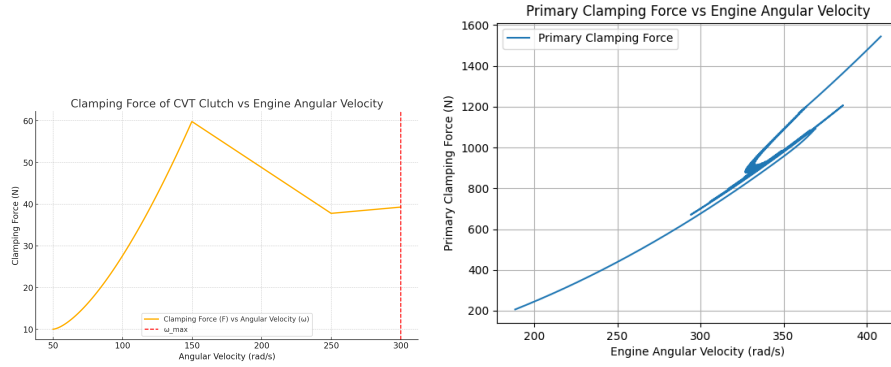


The vehicle's acceleration matches the general shape of the theoretical model. The slope of the theoretical model was simply an estimate, meant to capture the shape of the graph, and so is a bit less accurate than the other graphs. Despite this, both share a common structure and follow expected trends.

2. **Acceleration test-2:** MSE against experimental data
(SEE VNV EXTRA)

3.1.4 Clamping Forces

1. **Clamping forces test-1:** Graphical validation



The shape of both graphs above do not match. While the expected result is an initial sharp increase, which then leads to a steady decrease, followed finally by an increase at the end, here we can see what is effectively exclusively an increase with some oscillations. This difference can be explained thanks to two factors.

First, the oscillations arise due to the NO SLIP ASSUMPTION [LINK HERE], which result in an underdamped system.

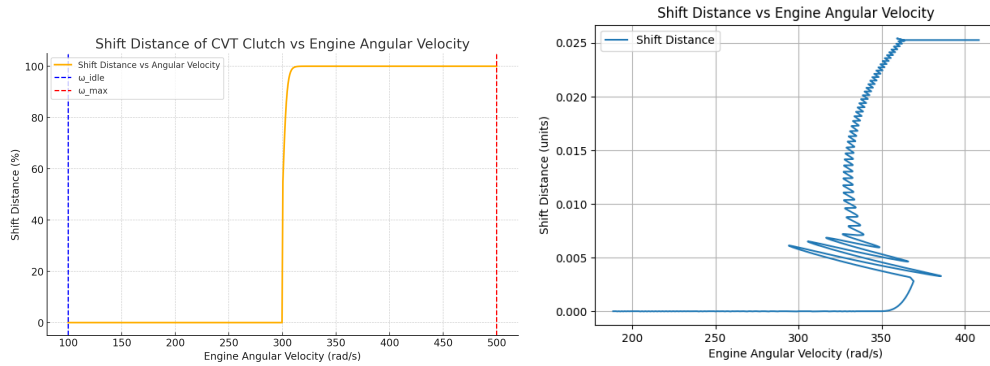
Secondly, the exclusive increase is due to a poor representation of the complex ramp geometry. While in the real world, we know the ramp begins linear, then transitions to a gentle curve that gives us the decrease in force as we shift, the simulation represents it as a linear line. This causes a more strict rising of the force at each corresponding angular velocity of the engine.

The impact this has on the system is quite miniscule. As long as the initial clamping forces which drive the shifting behaviour are correct, the majority of the system should behave as expected. Since our shifting occurs at one specific angular velocity, we need not worry about some of the extremities being too far off. Further, the real world downsides of having an ever-increasing clamping force would be an excess of heat,

which is ignored in our simulation in assumption NO HEAT [LINK HERE].

3.1.5 Shift

1. Shift test-1: Graphical validation 1

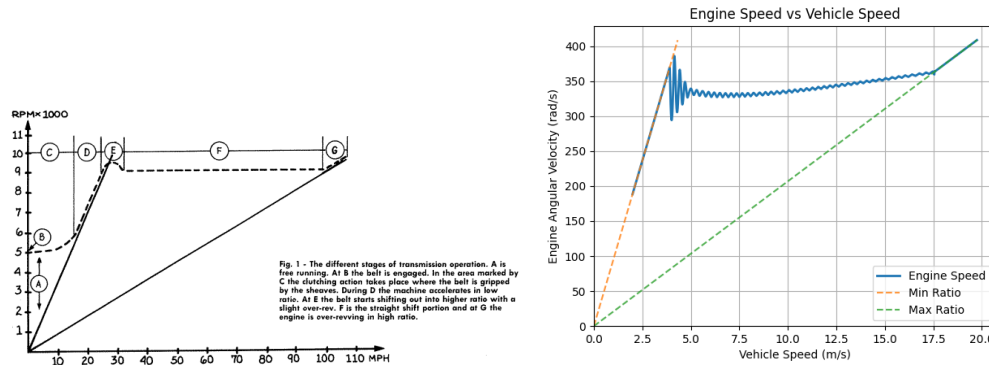


We can see the graphs are quite close in shape. Some key differences include:

- the magnitude at which we shift, which is variable and can be altered based on the input parameters.
- The oscillations in the simulation are due to the NO SLIP ASSUMPTION [LINK HERE], which cause an underdamped system.
- The slight slope within the simulation. This is due to the poor ramp representation alongside other input parameters. Will be discussed more in Shift test-3.

2. Shift test-2: MSE against experimental data 1 (SEE VNV EXTRA)

3. Shift test-3: Graphical validation 2



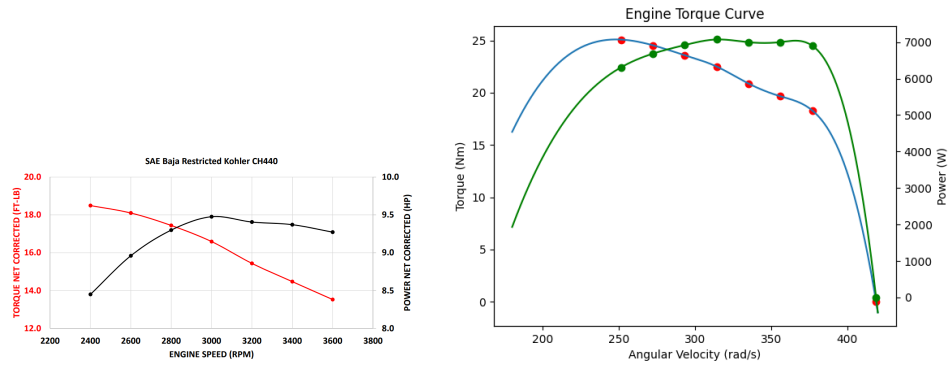
The shift curve seen here shows much about the system, as so we will go over each section within the graph.

- Phase A to C: Due to the no slip assumption, it is unreasonable to model these portions. Were the engine tied to the vehicle's speed without slip, at low velocities the engine would be spinning lower than it is capable of maintaining, and would thus kill the system. The solution in our simulation is to skip this portion, beginning at an initial velocity of around 3.5m/s.
- Phase D and E: This portion is modelled quite well. Here we see the vehicle and engine gaining speed at the low-ratio gear. We also see a slight overshoot thanks to the momentum of the system.
- Phase F: This is the shifting phase, which has the bulk of the calculations in our system affecting. Overall, a similar shape is reflected in both, with a mostly horizontal line. The slight slope in the simulation arises as we begin to shift too slowly, which allows the engine to gain speed. This can be attributed to several factors, but the most prominent is the poor ramp representation. The ramp is modelled as a linear line, which causes the system to shift too slowly. This is a minor issue, as the system still shifts at the correct time, but the speed at which it shifts is too slow.
- Phase G: In the final phase, we see the system accelerate at the high-ratio gear. Both graphs match exactly in this portion.

4. **Shift test-2:** MSE against experimental data 2 (SEE VNV EXTRA)

3.1.6 Engine Dynamics

1. Engine test-1: Graphical validation



As seen in these two graphics, all points within the theoretical figures are represented exactly in the simulation. The only addition is seen via a point at our max engine RPM of 4000, which is limited by the official Baja SAE rules [LINK HERE]. The produced torque at this point drops to 0, as a restrictor plate ensures no additional power may be produced beyond this speed.

3.2 User Interface

1. User Interface test-1: Input Parameters

The input parameters are loaded with the default values. The user can adjust the parameters and the simulation will run with the new parameters. The user can also save the parameters to a file and load them back in. The user can also export the simulation data to a file.

2. User Interface test-2: User Interface

When the user launches the application they are presented with a main menu. From here they can navigate to the simulation screen where they can adjust the parameters and run the simulation

3. User Interface test-3: Viewing Data Outputs

The user can view the data outputs in the simulation screen. The user has an option to view the data displayed in a graph format and the

user can see the position, velocity, acceleration, and shift distance of the car over time.

4. **User Interface test-4:** Saving and Exporting Data

From the results screen the user can save the parameters inputted to the simulation to a file. The user can also export the simulation data to a csv file for further analysis.

4 Nonfunctional Requirements Evaluation

This section will cover the evaluation of the Nonfunctional Requirements.

4.1 Accuracy

The accuracy test involves the outputs of the following Functional Test cases: **Position test-2**, **Velocity test-2**, **Acceleration test-2**, **Shift test-2** and **Shift test-4**. The following Accuracy test is to be completed in the VNV EXTRA.

1. **Accuracy test-1:** This test will take the outputted data of above listed functional tests. As each of these tests will output the MSE, each MSE should fall within 0.2 of 0. A range within 0.2 of 0 for each MSE outputted will indicate an accurate system.

4.2 Usability

The Usability/Understandability survey remains in progress at this time and results will be discussed in the [Usability Report](#). Therefore, Usability test-1 and Usability test-2 have not been fully completed yet, however as they are in progress these tests will be completed as future work.

1. **Usability test-1:** Navigating Main Interface
Survey question: On a scale of 1-5 with 1 being extremely difficult and 5 being extremely easy, how easy was it to navigate the main interface?
2. **Usability test-2:** Use of Most Common Features
Survey question: For the following main features: Inputting parameters, Adjusting parameters, Viewing data outputs, Saving and export-

ing data. Rate each feature on a scale of 1-5 with 1 being extremely difficult and 5 being extremely easy

4.3 Maintainability

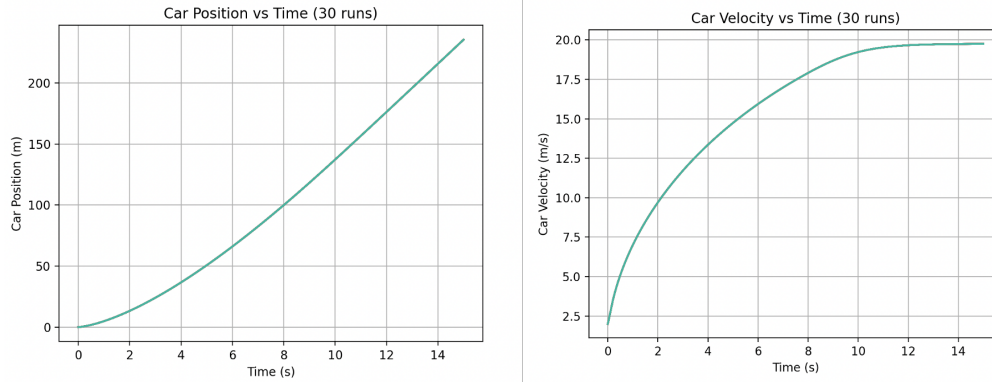
The maintainability tests are designed to test how maintainable the system is given likely future changes.

1. Maintainability test-1

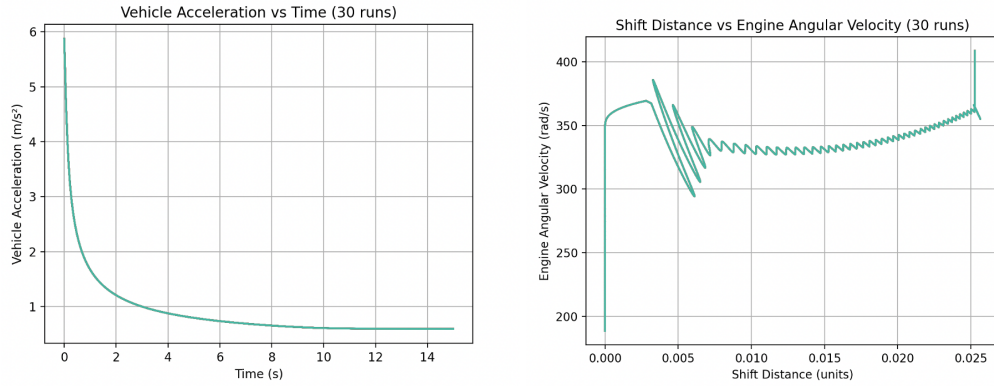
This test was manually completed where the amount of time and number of lines of code will be recorded when implementing the changes that correspond to the 2023 CVT configuration. Implementation of the 2023 CVT parameters takes at most 20 minutes with modifications to appropriately 26 lines of code in the `car_specs.py`. Thus, the system is easily maintainability and the number of lines modified and time taken is minimal given a total change in parameters of the CVT.

4.4 Verifiability

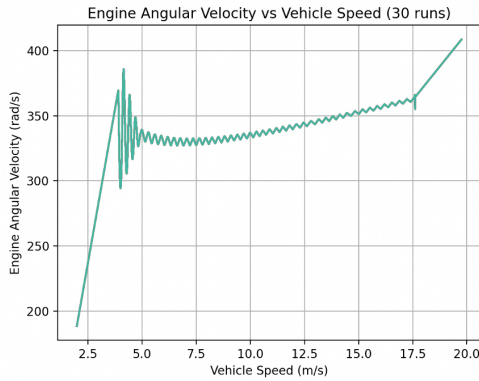
The tests for verifiability involve completing **Position test-1**, **Velocity test-1**, **Acceleration test-1**, **Shift test-1** and **Shift test-3**. For each of the above tests, they will be run 30 times with the same input parameters to verify that the output produced is the same each time.



The graphs above show the Car Position vs Time(Left) and the Car Velocity vs Time(Right) after 30 simulations with the same inputs. These tests correspond to **Position test-1** and **Velocity test-1**.



The graphs above show the Car Acceleration vs Time(Left) and the Shift Distance vs Engine Angular Velocity(Right) after 30 simulations with the same inputs. These tests correspond to **Acceleration test-1** and **Shift test-1**.



The graph above show the Engine Angular Velocity vs Vehicle Speed. These tests correspond to **Shift test-3** and **Velocity test-1**.

As seen, based on the graphs above, there is little to no variation when performing the tests: **Position test-1**, **Velocity test-1**, **Acceleration test-1**, **Shift test-1** and **Shift test-3** 30 times on the same input data. This passes the test for verifiability.

4.5 Understandability

The Usability/Understandability survey remains in progress at this time and results will be discussed in the [Usability Report](#). Therefore, Understandability test-1 and Understandability test-2 have not been completed yet, however

as they are in progress these tests will be completed as future work.

1. **Understandability test-1**

Survey question: For the following main features: Inputting parameters, Adjusting parameters, Viewing data outputs, Saving and exporting data. Was the purpose of each function clear, on a scale of 1-5 with 1 being very unclear and 5 being extremely clear.

2. **Understandability test-2: Understanding Simulation Outputs**

Survey question: On a scale of 1-5, with 1 being very unclear and 5 being extremely clear, how well did you understand the simulation results and output?

4.6 Reusability

The reusability tests are designed to assess how easily the system can be adapted to new or modified configurations.

1. **Reusability test-1**

This test was manually performed by the teams, where the time taken and number of lines of code modified were recorded when implementing the 2023 CVT configuration. Implementation of the 2023 CVT parameters requires at most 20 minutes and involves modifications to approximately 26 lines of code in the `car_specs.py` file. These minimal changes demonstrate the system's high reusability, as it can be quickly adapted to new CVT configurations with little effort and modification.

5 Comparison to Existing Implementation

Not applicable for this project.

6 Unit Testing

6.1 Back End Unit Testing

The back end was fully covered by unit tests except for a several files which were not suited for unit testing as they were mainly constants or did not provide functionality that could be tested.

The test structure that was created was to essentially mirror how the code-base is organized. There is a test folder which houses all the tests, then inside that there is a simulations and utils folder which contain mirrored test files of the actual files under src/simulations or src/utils.

The tests were written using the built-in unittest module in python. The tests were run using the command `coverage run -m unittest discover -s test/simulations -s test/utils`. This command runs all the tests in those two folders using the coverage library.

A coverage report was generated using the command `coverage report -m`.

This command generates a report that shows the percentage of code that was covered by the tests. The report also shows which lines were not covered by the tests. This can be seen in section 11 of this document.

6.2 Front End Unit Testing

The front end communication protocol was fully covered by unit tests besides the function that calls the python script since it is dependent on the back end Implementation.

The tests are stored in a separate project within the front end solution. They are written using the MS Unit Testing Framework and are run using the dotnet test command.

A coverage report was generated using the JetBrains dotCover tool which shows the percentage of code that was covered by the tests.

7 Changes Due to Testing

[This section should highlight how feedback from the users and from the supervisor (when one exists) shaped the final product. In particular the feedback from the Rev 0 demo to the supervisor (or to potential users) should be highlighted. —SS]

7.1 Front End Changes

On the front end, many changes were made to support unit testing. The communication protocol was separated from the main Unity project since Unity was not compatible with the MS Unit Testing Framework.

Moving the communication protocol into a separate project allowed for the simplification of the code base by isolating responsibilities and improving modularization.

There were also changes on the front end to support the requested changes from the Rev 0 demo. The input parameters were updated to be stored in a csv file and read from there.

These changes were to facilitate the implementation of uploading and downloading the parameters from the front end which was a requested feature from the Rev 0 demo.

8 Automated Testing

Both back and front end sets of unit tests were automated and added to the CI/CD pipeline. Now whenever there is a commit it must pass all the tests in order to be verified. If there is an error it will fail and state which tests failed. This is a good way to ensure that the code is always working as expected.

As well the back end coverage report is also generated in the CI/CD run so you can see how much of the code is being covered by tests at that moment.

The configuration for the CI/CD can be seen here: <https://github.com/gr812b/CVT-Simulator/blob/develop/.github/workflows/ci.yaml>

9 Trace to Requirements

| Requirement | Test(s) |
|-------------|---|
| R1 | Position test-2, Velocity test-2, Acceleration test-2, Shift test-4 |
| R2 | Acceleration test-1 |
| R3 | Velocity test-1 |
| R4 | Position test-1 |
| R5 | Clamping forces test-1 |
| R6 | Clamping forces test-1 |
| R7 | Shift test-1, Shift test-2, Shift test-3 |
| R8 | Shift test-1, Shift test-2, Shift test-3 |
| R9 | Engine test-1 |
| R10 | User Interface test-1 |
| R11 | User Interface test-1 |
| R12 | User Interface test-2 |
| R13 | User Interface test-3 |
| R14 | User Interface test-4 |
| R15 | Compatibility test-1 |
| R16 | Compatibility test-1 |

Table 1: System Functional Requirements and Corresponding Tests

| Requirement | Test(s) |
|-------------|--|
| NFR1 | Accuracy test-1 |
| NFR2 | Useability test-1, Useability test-2 |
| NFR3 | Maintainability test-1 |
| NFR4 | Verifiability test-1 |
| NFR5 | Understandability test-1, Understandability test-2 |
| NFR6 | Reusability test-1 |

Table 2: System Nonfunctional Requirements and Corresponding Tests

10 Trace to Modules

11 Code Coverage Metrics

```
PS C:\Users\travi\CVT-Simulator> coverage report
```

| Name | Stmts | Miss | Cover |
|---------------------------------------|-------|------|-------|
| src\constants\car_specs.py | 24 | 0 | 100% |
| src\utils\argument_parser.py | 32 | 0 | 100% |
| src\utils\conversions.py | 13 | 0 | 100% |
| src\utils\simulation_result.py | 31 | 13 | 58% |
| src\utils\system_state.py | 13 | 0 | 100% |
| src\utils\theoretical_models.py | 64 | 2 | 97% |
| test\utils\test_argument_parser.py | 19 | 1 | 95% |
| test\utils\test_conversions.py | 30 | 1 | 97% |
| test\utils\test_simulation_result.py | 37 | 1 | 97% |
| test\utils\test_system_state.py | 26 | 1 | 96% |
| test\utils\test_theoretical_models.py | 35 | 1 | 97% |
| TOTAL | 324 | 20 | 94% |

Figure 1: Back End Code Coverage

| | | |
|--------------------------------------|------|--------|
| CommunicationProtocol | 80% | 27/133 |
| (1.0.0.0, NETStandard, Version=v2.0) | 80% | 27/133 |
| CommunicationProtocol | 80% | 27/133 |
| Senders | 46% | 26/48 |
| PythonRunner | 0% | 23/23 |
| InputStore | 82% | 3/17 |
| Parameter | 100% | 0/8 |
| Receivers | 99% | 1/85 |
| InputParameters | 94% | 1/18 |
| SimulationResult | 100% | 0/12 |
| CSVReader<T> | 100% | 0/17 |
| DataPoint | 100% | 0/38 |

Figure 2: Front End Code Coverage

References

Appendix — Reflection

The information in this section will be used to evaluate the team members on the graduate attribute of Reflection.

The purpose of reflection questions is to give you a chance to assess your own learning and that of your group as a whole, and to find ways to improve in the future. Reflection is an important part of the learning process. Reflection is also an essential component of a successful software development process.

Reflections are most interesting and useful when they're honest, even if the stories they tell are imperfect. You will be marked based on your depth of thought and analysis, and not based on the content of the reflections themselves. Thus, for full marks we encourage you to answer openly and honestly and to avoid simply writing "what you think the evaluator wants to hear."

Please answer the following questions. Some questions can be answered on the team level, but where appropriate, each team member should write their own response:

1. What went well while writing this deliverable?
2. What pain points did you experience during this deliverable, and how did you resolve them?
3. Which parts of this document stemmed from speaking to your client(s) or a proxy (e.g. your peers)? Which ones were not, and why?
4. In what ways was the Verification and Validation (VnV) Plan different from the activities that were actually conducted for VnV? If there were differences, what changes required the modification in the plan? Why did these changes occur? Would you be able to anticipate these changes in future projects? If there weren't any differences, how was your team able to clearly predict a feasible amount of effort and the right tasks needed to build the evidence that demonstrates the required quality? (It is expected that most teams will have had to deviate from their original VnV Plan.)