TransitLab SimMETRO

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ONE

INTRODUCTION

1.1 Project Overview

TransitLab SimMETRO is a sophisticated simulation tool developed upon decades of research (Koutsopoulos and Wang [KW07] and Zhou [Zho22]) and development to address the operational challenges faced by heavy rail systems in major metropolitan areas, particularly during peak periods when demand is highest. This tool provide microscopic simulation model for heavy rail systems, enabling detailed analysis of train behaviors, signaling systems (fixed-block and moving block), and interactions between trains and passengers. By employing TransitLab SimMETRO, researchers can evaluate various operating strategies such as skip-stop, station consolidation, and dwell control to mitigate capacity bottlenecks.

The simulation framework is built using Python in a unix environment, ensuring robust performance and flexibility. The model's accuracy and reliability can be further enhanced through a calibration process using data from Operational Control Systems [WK11]. Numerous visualization tools allow users to analyze simulation outputs.

Numerous case studies (see Zhou *et al.* [ZKS20] and Zhou and Koutsopoulos [ZK22]) demonstrate how MIT Transit-Lab SimMETRO has helped agencies address congestion, improve service reliability, and support long-term planning decisions.

1.2 Features

- 1. Detailed modeling of signal systems, including both fixed-block and moving-block, with precise train movement simulations at the individual vehicle level.
- 2. Accurate dwell time modeling at stations to reflect real-world scenarios.
- 3. Realistic passenger boarding and alighting behaviors.
- 4. Implementation of headway-based dispatching to model stochasticities in rail operations.
- 5. Comprehensive simulation outputs for thorough analysis.
- 6. Multiple visualization tools available for detailed examination of simulation data.
- 7. Customizable train movement models to suit various rail systems.

1.3 License

The project License is yet to be determined. Please contact the development team for more information.

TWO

SETUP GUIDE

This project uses Pipenv for dependency management and packaging. You can learn about the dependencies looking at the Pipfile at the project root directory. Assuming you have a working version of pip, you can install Pipenv using pip:

\$ pip install --user pipenv

Pipenv will take care of installing dependencies and creating the virtual environment. Run the following command from the project root directory (where the Pipfile and Pipfile lock are located):

\$ pipenv install

You can activate the virtual environment using:

\$ pipenv shell

Depending on Python versions available on your system you may get an error like:

```
Error: the specified Python version (3.8) is not available on your system.
```

It is recommended to install the required Python version using pyenv. You can install pyenv using the instructions at https://github.com/pyenv/pyenv?tab=readme-ov-file#installation.

You may need to reactivate your shell after installing pyenv/pipenv to make sure they are added to the PATH.

Once you have pyenv installed, Pipenv will ask you if you like to use pyenv to install the required Python version. You can say yes and Pipenv will install the required Python version in the virtual environment.

THREE

GETTING STARTED

3.1 Quick Start

- 1. Prepare the input files:
 - Ensure you have the following files in the *inputs* directory:
 - infra.json: Infrastructure data
 - slow_zones.json: Slow zone definitions
 - demand/odx_demand.csv: Passenger demand data
 - schedules/empirical_schedule.json: Train schedule data
- 2. Configure the simulation:
 - Open the load-balance/config.yaml file
 - · Adjust the following parameters as needed:
 - $\ simulation.number_of_replications \\$
 - simulation.start_time_of_day
 - simulation.end_time_of_day
 - demand_level
 - station
 - short_turning
 - logger.should_log_trajectories
 - logger.log_interval
- 3. Run the simulation:

```
python -m transit_lab_simmetro.simulation_runner.runner
```

- 4. Check the output:
 - Look for the generated log files in the specified log folder (default: log_folder_path)
 - You'll find CSV and JSON files with various simulation data

3.2 Understanding the Inputs and Config

- 1. Infrastructure (infra.json):
 - Defines blocks, stations, and path information for Northbound and Southbound directions
- 2. Slow Zones (slow_zones.json):
 - Specifies areas with reduced speed limits
- 3. Demand Data (odx_demand.csv):
 - Contains passenger arrival rates at 15-minute intervals for weekdays and non-weekdays for each OD pair
- 4. Schedule Data (empirical_schedule.json):
 - Defines train dispatch times and routes
- 5. Configuration (config.yaml):
 - simulation: Set replication count, start and end times
 - demand_level: Adjust overall passenger demand. Used as a multiplier to uniformly scale demand.
 - station: Specify holding station (e.g., "O-Hare" or "Clark/Lake")
 - short_turning: Set short turning location ("UIC" or "Western")
 - logger: Configure logging options

By adjusting these inputs and configurations, you can simulate various scenarios and analyze the rail system's performance under different conditions.

FOUR

USAGE

4.1 Basic Usage

Explain how to use the project with simple examples.

4.2 Advanced Usage

Dive into more complex use cases and features.

8 Chapter 4. Usage

FIVE

CONFIGURATION

5.1 Configuration Options

Document configuration options, environment variables, etc.

5.2 Default Configuration

Explain the default setup and how to customize it.

ARCHITECTURE

6.1 Components Overview

6.1.1 Infrastructure Module

```
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.AbstractBlock
     Bases: ABC
     __init__(block_id: str, block_alt_name: str, visible_distance: float, length: float, default_speed_code:
                float, station: Station | None = None)
     abstract current_speed_code(requesting_train: Train) → float
     abstract property is_occupied: bool
     abstract is_occupied_by(train: Train) \rightarrow bool
     set_slow_zone(speed_limit: float)
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.Block
     Bases: AbstractBlock
     __init__(*args, speed codes to communicate: Dict[str, float] | None = None, **kwargs)
     activate(entering\_train: Train) \rightarrow None
     add\_communicated\_speed\_code(block\_id: str, speed\_code: float) \rightarrow None
     add\_observer: SignalControlCenter) \rightarrow None
     block_logger: BlockActivationLogger | None = None
     current_speed_code(requesting_train: Train) → float
     deactivate(exiting\_train: Train) \rightarrow None
     property id_of_last_train: str | None
     property is_occupied: bool
     is_occupied_by(train: Train) \rightarrow bool
     property last_train_visit_time: float
```

```
notify_observers() \rightarrow None
     remove\_communicated\_speed\_code(block\_id: str) \rightarrow None
     set_slow_zone(speed_limit: float)
class
transit_lab_simmetro.simulation_engine.infrastructure.__init__.DispatchingBlockDecorator
     Bases: Block
     __init__(block: Block, path: Path, dispatch_margin: float = 120, upstream_blocks: List[str] = [])
     activate(entering\_train: Train) \rightarrow None
     is\_it\_clear\_to\_dispatch() \rightarrow bool
     property last_train_visit_time: float
     ready_to_dispatch(train: Train) → bool
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.
DispatchingMovingBlockDecorator
     Bases: MovingBlock
     __init__(block: MovingBlock, path: Path, dispatch_margin: float = 120, upstream_blocks: List[str] = [])
     activate(entering\_train: Train) \rightarrow None
     is\_it\_clear\_to\_dispatch() \rightarrow bool
     property last_train_visit_time: float
     ready_to_dispatch(train: Train) \rightarrow bool
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.MovingBlock
     Bases: AbstractBlock
     __init__(*args, **kwargs)
     activate(entering train: Train) \rightarrow None
     property civil_speed_limit: float
     current_speed_code(requesting_train: Train) → float
     property current_train: Train | None
     deactivate(exiting\_train: Train) \rightarrow None
     property is_occupied: bool
     is\_occupied\_by(train: Train) \rightarrow bool
     next_train(requesting_train: Train) → Train | None
     register\_moving\_block\_control\_center(moving\_block\_control) \rightarrow None
     property sorted_current_train_list: List[Train]
```

```
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.MovingBlockControl
      Bases: object
      __init__(blocks: List[MovingBlock], safety margin: float = 200) \rightarrow None
      get_distance_to_next_train(asking_train: Train) → float
      get\_speed\_code(asking\_train: Train, asking\_block: MovingBlock) \rightarrow float
      needed_braking_distance(asking_train: Train) → float
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.
OffScanSymptomaticBlockDecorator
      Bases: Block
      __init__(block: Block, path: Path, offscan_probability: float = 0.01)
      activate(entering\_train: Train) \rightarrow None
      current_speed_code(requesting_train: Train) → float
      \verb"set_unsymptomatic() \to None
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.Path
      Bases: object
      __init__(direction: str, blocks: List[MovingBlock | Block], slow_zones: List[SlowZone] = [])
      copy()
      get_all_stops_ahead(block_index: int) \rightarrow List[Station]
      get_all_stops_ahead\_which_are\_served(block\_index: int) \rightarrow List[Station]
      get_block_by_id(block\ id: str) \rightarrow MovingBlock \mid Block
      \texttt{get\_block\_index\_by\_id}(block\_id: str) \rightarrow \text{int}
      \texttt{get\_distance\_to\_the\_next\_station}(current\_block\_index: int, current\_location\_on\_block: float) \rightarrow
      get_next_station(current\_block\_index: int) \rightarrow Station \mid None
      get_next_train(current\_block\_index: int) \rightarrow Train \mid None
      get\_previous\_train(current\_block\_index: int) \rightarrow Train \mid None
      get\_total\_length() \rightarrow float
      get_total_travelled_distance(current_block_index: int, distance_travelled_in_current_block: float)
                                            \rightarrow float
      is\_inspected() \rightarrow bool
      is\_short\_turn() \rightarrow bool
      is\_short\_turned\_at\_this\_station(station: Station) \rightarrow bool
      make_dispatching_block(block_id: str, dispatch_margin: float = 120, upstream_blocks: List[str] = [])
```

```
make_offscan_block(block_index: int, offscan_probability: float)
     path\_distance\_alignment() \rightarrow None
     set_block_slow_zone(block_id: str, speed_limit: float)
     short_turn(train: Train)
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.SignalControlCenter
     Bases: object
     __init__(blocks: List[Block])
     get_block_by_id(block_id: str) \rightarrow Block \mid None
     restore_speed_codes_to_upstream_blocks(block: Block) \rightarrow None
     send\_speed\_codes\_to\_upstream\_blocks(block: Block) \rightarrow None
     update(block: Block) \rightarrow None
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.SlowZone
     Bases: object
      __init__(block_id: str, reduced_speed_limit: float)
     classmethod from_dict(data: dict) \rightarrow SlowZone
     to\_dict() \rightarrow dict
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.Station
     Bases: object
     __init__(station_name: str, location_relative_to_block: float, direction: str, arrival_rates: ArrivalRate)
     board_passengers_based_on_destiations_and_probability(train_capacity: int,
                                                                        served_destinations: List[str],
                                                                        probability_of_boarding_any_train:
                                                                       float) \rightarrow List[Passenger]
     board_passengers_onto_train(train_capacity: int, served_destinations: List[str]) \rightarrow List[Passenger]
     generate\_and\_add\_passengers(train: Train, holding\_time: float = 0) \rightarrow None
     \texttt{get\_dwell\_time}(door\_metrics: List[Tuple(int, int, int)]) \rightarrow \texttt{float}
     property last_train_visit_time: float
     simulation: Simulation
     station_logger: StationLogger | None = None
class transit_lab_simmetro.simulation_engine.infrastructure.__init__.Terminal
     Bases: Block
     __init__()
     activate(entering\_train: Train) \rightarrow None
     current_speed_code(requesting_train: Train) → float
```

6.1.2 Passenger Module

```
class transit_lab_simmetro.simulation_engine.passenger.__init__.ArrivalRate
     Bases: object
     \_\_init\_\_(filename, demand\_factor: int = 1)
     get_a_i(current_hour: float, current_weekday: bool, start_station: str, critical_station: str, direction: str)
               \rightarrow float
     get_all_destination_stops_for_origin(origin_stop: str) \rightarrow List[str]
     get_all_destination_stops_for_origin_and_direction(origin_stop, direction) \rightarrow List[str]
     get_all\_previous\_stops\_for\_station\_and\_direction(station: str, direction: str) \rightarrow List[str]
     get_lambda_bar(current_hour: float, current_weekday: bool, start_station: str, critical_station: str,
                        direction: str) \rightarrow float
     get_lambda_for_station(current_hour: float, current_weekday: bool, station: str, direction: str) 	o float
     get_p_for_station(current_hour: float, current_weekday: bool, station: str, direction: str) <math>\rightarrow float
     get_smoothed_rate(current_hour, current_weekday, origin_stop, destination_stop)
     is_southbound_trip(origin_stop, destination_stop)
     sort\_stations\_by\_direction(direction) \rightarrow List[str]
class transit_lab_simmetro.simulation_engine.passenger.__init__.Passenger
     Bases: object
     __init__(arrival_time: float, origin: str, direction: str, destination: str)
     property alighting_time
     property boarding_time
     denied_boarding()
     property journey_time
     passenger_logger: PassengerLogger | None = None
     set_not_loggable()
     property travel_time
     property waiting_time
class transit_lab_simmetro.simulation_engine.passenger.__init__.PassengerGenerator
     Bases: object
     __init__(arrival_rate: ArrivalRate)
     generate_passengers(current_hour: float, current_weekday: bool, boarding_stop: str, alighting_stop: str,
                              delta\_t\_in\_seconds: float) \rightarrow list
```

6.1.3 Simulation Module

```
class transit_lab_simmetro.simulation_engine.simulation.simulation.Simulation
     Bases: object
     __init__(schedule: Schedule | BaseSchedule, path: Dict[str, Path], signal_control_center:
               MovingBlockControl | SignalControlCenter, train_speed_regulator: str, time_step: float = 0.5,
               start_hour: float = 5.0, is_weekday: bool = True, total_time: float = 14400)
     get_current_hour() → float
     is_weekday() \rightarrow bool
     remove_train(train: Train) \rightarrow None
     run() \rightarrow None
     simulation_logger: SimulationLogger | None = None
class transit_lab_simmetro.simulation_engine.simulation.simulation.SimulationContext
     Bases: object
     __init__(simulation: Simulation)
6.1.4 Train Module
class transit_lab_simmetro.simulation_engine.train.__init__.DummyTrain
     Bases: Train
     layover_and_turnback() → None
     log() \rightarrow None
     should_log() \rightarrow bool
     simulation: Simulation
class transit_lab_simmetro.simulation_engine.train.__init__.DummyTrainDecorator
     Bases: DummyTrain
     __init__(train: Train)
     simulation: Simulation
class transit_lab_simmetro.simulation_engine.train.__init__.Train
     Bases: object
     __init__(train_speed_regulator: TrainSpeedRegulator | TrainSpeedRegulatorCTA,
               train_passenger_manager: TrainPassengerManager, path: Path, starting_block_index: int = 0,
               dispatching_time: float | None = None, runid: str | None = None)
     property acceleration_in_fps2: float
     block_with_red_signals_in_sight() → Tuple[float | None, int | None]
     property current_block: BlockType
```

```
property current_speed_code: float
     delete() \rightarrow None
     property distance_to_next_block: float
     property distance_to_next_station: float
     distance\_traveled\_from\_the\_start\_of\_block(asking\_block: BlockType) \rightarrow float
     property first_block_after_station: BlockType | None
     classmethod generate_train_id()
     get_all_stops_ahead() \rightarrow list[Station]
     get_next_station() → Station
     property location_from_terminal: float
     log() \rightarrow None
     property next_block: BlockType
     property previous_block: BlockType
     set\_state\_to\_dwelling\_at\_station(station: Station) \rightarrow None
     should_log() \rightarrow bool
     simulation: Simulation
     property speed_in_fps: float
     property time_step: float
     property total_travelled_distance: float
     property total_travelled_distance_from_dispatch: float
     train_logger: TrainLogger | None = None
     update() \rightarrow None
     update\_block() \rightarrow None
     update\_distance\_travelled() \rightarrow float
     update\_speed() \rightarrow None
class transit_lab_simmetro.simulation_engine.train.__init__.TrainPassengerManager
     Bases: object
     \_init\_(train_capacity: int, num_cars: int = 8, num_doors_per_car: int = 2, car_capacity: int = None,
               num\_seats\_per\_door: int = 20)
     alight_all_passengers(current_station, current_time)
     alight_passengers(current_station, current_time)
```

```
board_passengers(passengers, current\_time, car\_assignment\_weights: List[float] = [1, 3, 1, 1, 1, 1, 3, 1])
     get_door_metrics(alight_counts, boarding_counts)
     remaining\_capacity() \rightarrow int
     property total_passengers
class transit_lab_simmetro.simulation_engine.train.__init__.TrainSpeedRegulator
     Bases: object
     __init__(max_acceleration: float, normal_deceleration: float, emergency_deceleration: float)
     property braking_distance: float
     entered_symptomatic_block(symptomatic_block) \rightarrow None
     property normal_acceleration: float
     property normal_acceleration_in_fps2
     property normal_decceleration_in_fps2
     property planning_distance: float
     register_train(train: Train) \rightarrow None
     regulate_acceleration()
     property train: Train
     train\_stopped\_at\_station(station: Station) \rightarrow None
     update\_train\_speed() \rightarrow None
class transit_lab_simmetro.simulation_engine.train.__init__.TrainSpeedRegulatorCTA
     Bases: object
     __init__(max_acceleration: float, normal_deceleration: float, emergency_deceleration: float,
               desired\_speed\_range: tuple[float, float] = (0.8, 1.0)
     property braking_distance: float
     property braking_distance_for_station: float
     entered\_symptomatic\_block(symptomatic\_block: OffScanSymptomaticBlockDecorator) \rightarrow None
     property normal_acceleration: float
     property normal_acceleration_in_fps2
     property normal_decceleration_in_fps2
     property planning_distance: float
     register_train(train: Train) \rightarrow None
     regulate_acceleration()
     property train: Train
```

```
\label{eq:train_stopped_at_station} \textbf{train_stopped_at_station}(\textit{station}: Station}) \rightarrow None \\ \\ \textbf{update\_desired\_speed()} \rightarrow None \\ \\ \textbf{update\_train\_speed()} \rightarrow None \\ \\ \\ \end{matrix}
```

6.2 Data Flow

Explain how data flows through the system.

6.2. Data Flow

SEVEN

DEVELOPMENT

7.1 Development Environment Setup

Guide on setting up the development environment.

7.2 Build Instructions

Explain how to build the project from source.

7.3 Testing

Describe how to run tests.

EIGHT

CONTRIBUTION GUIDELINES

8.1 How to Contribute

Instructions for making contributions, including coding standards and the pull request process.

8.2 Community Guidelines

Code of conduct and how to get involved in the community.

NINE

API DOCUMENTATION

9.1 API Overview

High-level overview of the API.

9.2 Endpoints/Functions

Detailed descriptions of API endpoints/functions, including parameters, request/response formats, and examples.

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FAQS

Address common questions and issues.

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ELEVEN

TROUBLESHOOTING

11.1 Common Issues

List common issues and their solutions.

11.2 Getting Help

Information on where to ask questions or report issues.

TWELVE

CHANGELOG

12.1 Version History

List of changes for each version, including new features, bug fixes, and breaking changes.

CHAPTER

THIRTEEN

APPENDIX

13.1 Glossary

Definitions of terms used in the documentation.

13.2 Further Reading

Links to additional resources such as blog posts, tutorials, and papers.

CHAPTER

FOURTEEN

INDICES AND TABLES

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