SUMO Simulation (SimpleT Sensitivity Analysis)

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Note

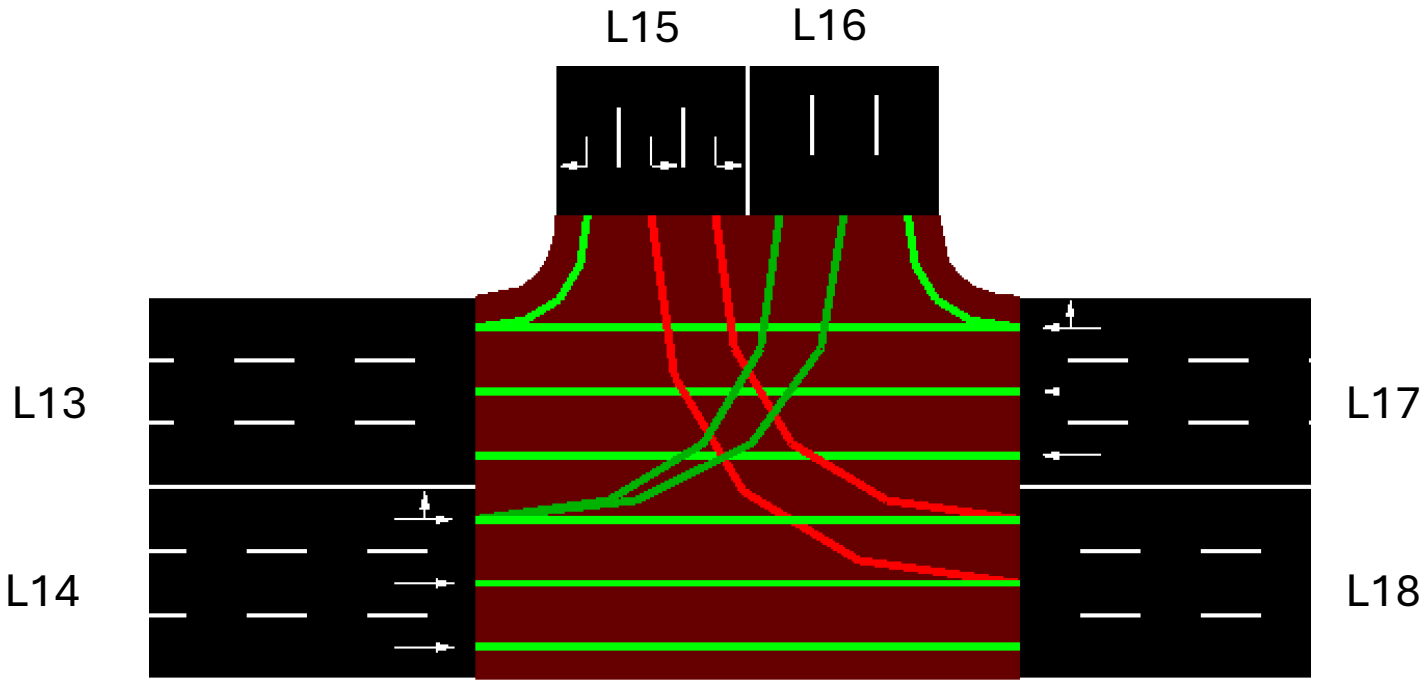
- The analysis shown in this presentation is based on model that hasn’t been validated in any way.
- Its purpose is to prototype an approach to analysis that can be used, in time, on a validated model.

What is Sobol sensitivity analysis

- Quantifies how much each input variable contributes to the variance in the output both on its own and through interactions with other variables.
- Helps in deciding which ‘inputs’ are important in determining an output, in this case, total vehicle emissions.
- Separates effects into first-order (individual) and higher-order (interaction) contributions.
- Provides total-order indices, showing the full influence of each input including all interactions, which helps identify dominant drivers of system behaviour.
- Works globally across the entire input space, not just around a single operating point, making it ideal for nonlinear and complex models.
- Uses a variance-based approach, meaning it directly measures how uncertainty in the inputs translates to uncertainty in the outputs.

Analysis Setup

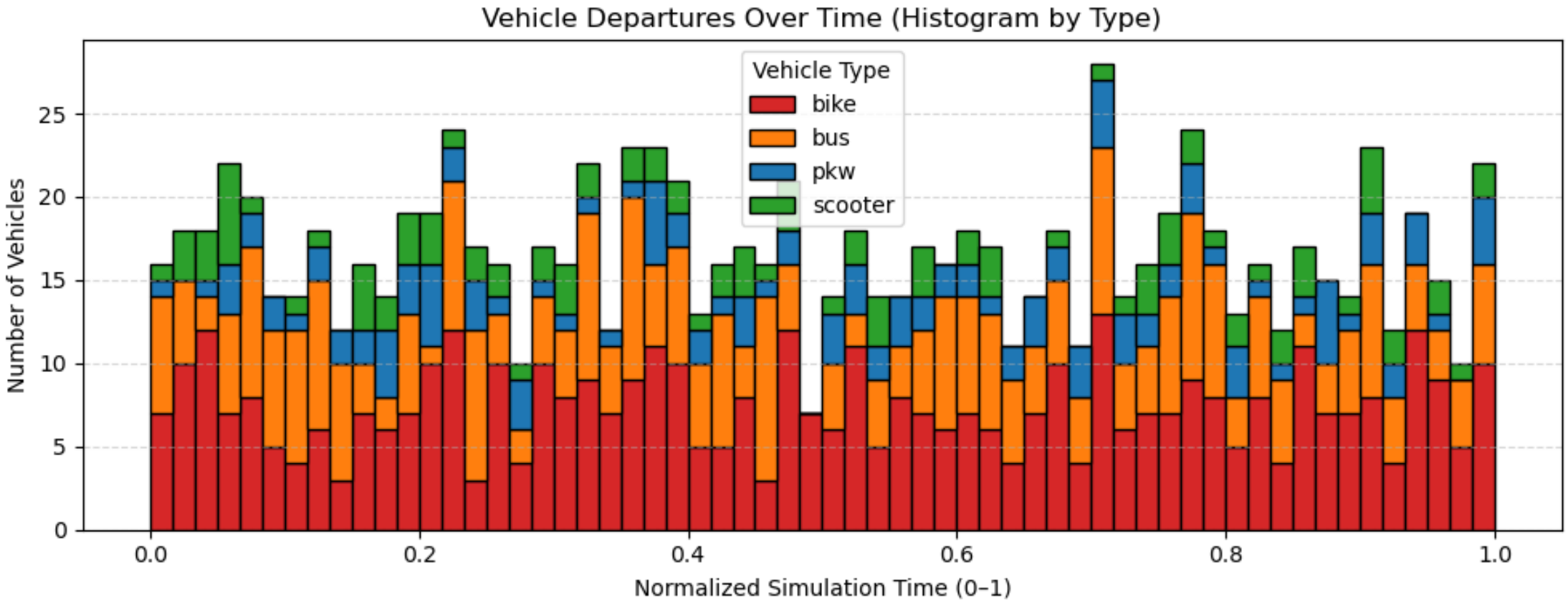
- Simple T junction
- Four vehicle types
  - pkw
  - bus
  - bike
  - scooter
- Traffic flows
  - L15 to L13 and L18
  - L14 to L16 and L18
  - L17 to L13 and L16



Analysis Setup

- Total number of vehicles is 1000
- Simulation time is 60 minutes
- Trips (*simpleT.rou.xml*) are generated using a defined vehicle distribution which changes in each simulation.
- The route file (*simpleT.rou.xml*) is generated using *random_route.py*
- A trip is assigned to a vehicle that is sampled from the defined vehicle distribution. As a consequence the trips that particular vehicles take between simulations will be different.
- The start time of the vehicle is randomly sampled. Vehicle departures over the period of the simulation are approximately uniform (see plot on next page).

Setup – an example of vehicle start times



Sobol Sensitivity

- Sobol sensitivity analysis is undertaken to determine the contribution of each vehicle class [pkw, bus, bike, scooter] on total variance in PM2.5 only
- Second order effects (interactions) are also evaluated.
- Sobol design was generated using *experimental_design.py*
- Sobol design was created with N * (2D+2) samples using quasi-random saltelli sampling
  - N = 512 (base sample size set for moderate accuracy)
  - D = 4 (number of inputs i.e. vehicle types)
  - Samples = 512 * (2*4+2) = 5120 (total simulations required)

Sobol Sensitivity

- 5120 simulations are run using vehicle distributions from sobol design taking around 7 hrs
- Total PM2.5 emissions are added, for each simulation separately, after all simulations have completed using functions defined in *sumo_interface.py*
- Results analysis and plotting is undertaken using script *sensitivity_study_analysis.py*

Sobol Sensitivity - Results

- First order terms (main effects)

main effect contribution to variance

total variance including higher order effects

confidence interval

Variable	S1	S1_conf	ST	ST_conf
bus	**0.700284**	0.101070	**0.751646**	0.100126
bike	**0.088004**	0.040740	0.138520	0.024786
pkw	**0.079886**	0.041794	0.118557	0.023936
scooter	**0.078712**	0.039200	0.104499	0.022015

- Results show
  - ‘bus’ influences PM2.5 variance the most
  - There is some interaction but most of its influence is first order
  - ‘bike’ influences PM2.5 second variance the most (note that this influence is –ve)
  - In total 94.7% variance is ‘explained’ by first order terms

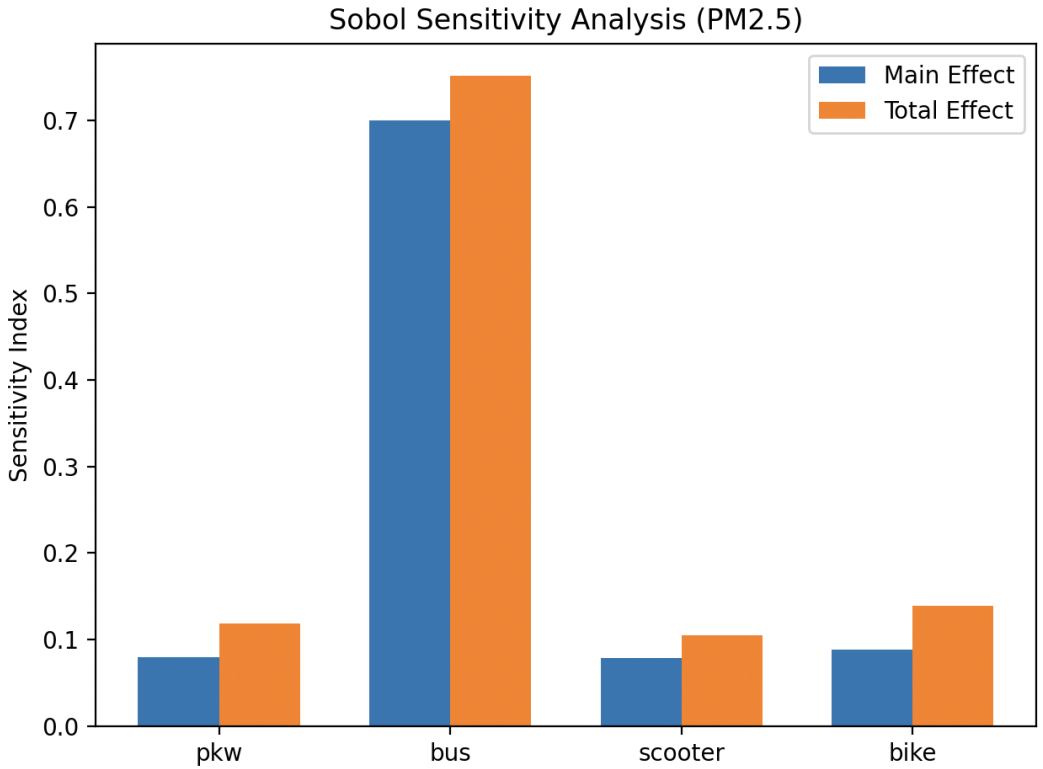
Sobol Sensitivity - Results

- Second order terms (interaction effects)

Variable Pair	S2	S2_conf
(pkw, scooter)	0.012486	0.074977
(bus, bike)	0.005288	0.124659
(pkw, bus)	0.004507	0.067788
(bus, scooter)	0.002921	0.122945
(pkw, bike)	0.000203	0.069756
(scooter, bike)	-0.010042	0.070251

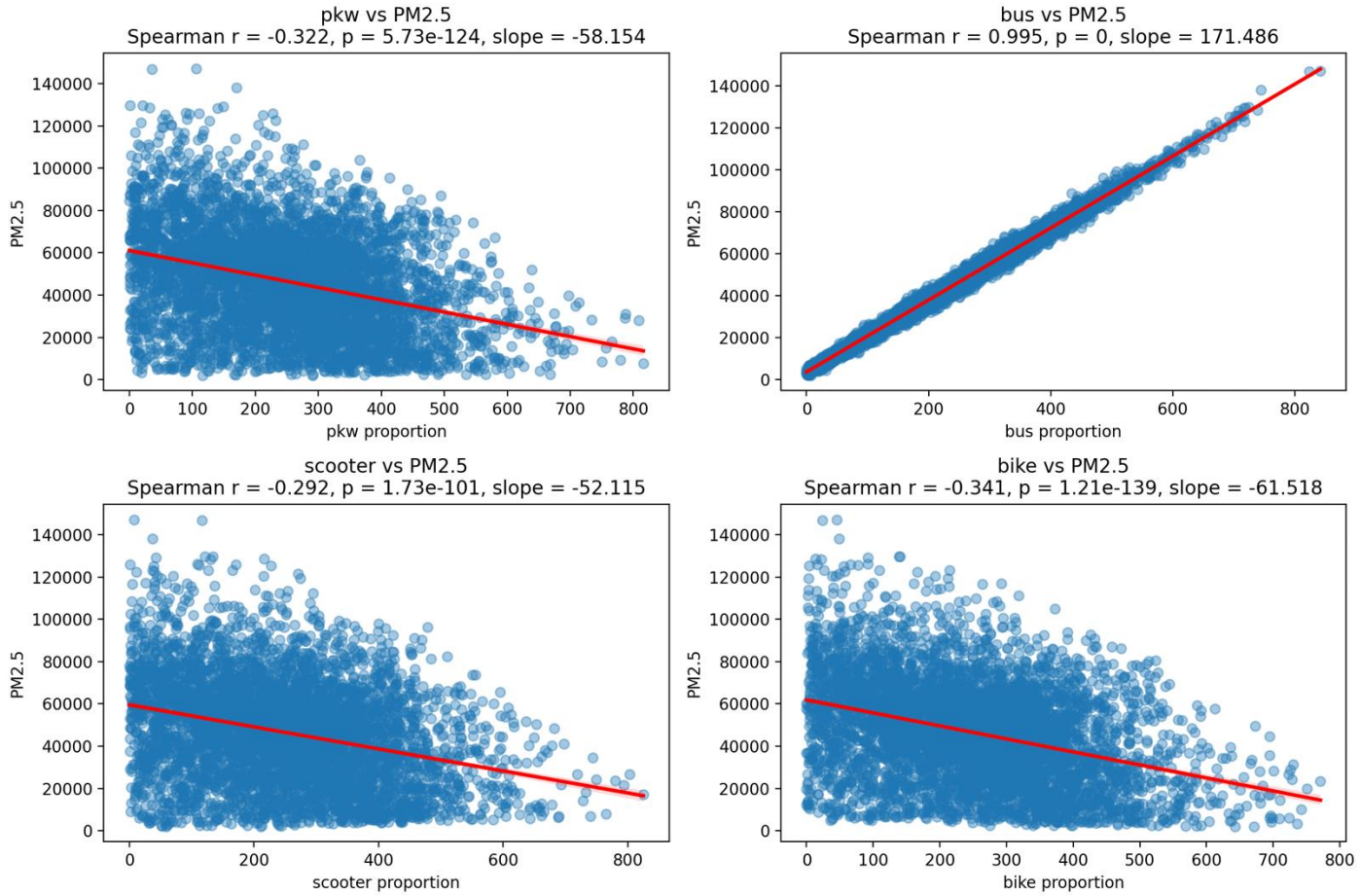
- Second order terms contribute significantly less to variance and confidence levels suggest that it may be possible to ignore them (further evaluation is required).
- Only 1.5% of variance is ‘explained’ by second order interactions
- ..and 3.7% of variance is ‘explained’ by higher order interactions and the randomness (trip assignment) in the model

Sobol Sensitivity - Results



- As can be seen from the summary above ‘main effects’ are of greatest influence to variance.

Sobol Sensitivity - Results



Sobol Sensitivity - Results

- Interesting results, that at first glance contradict (naive) intuition.
  - More pkw, bike and scooter decreases PM2.5
  - More bus increases PM2.5
- The above is a limitation of the approach i.e. having fixed vehicle numbers
  - Need to think about how to deal with the above
  - Suggest a ‘replacement factor’ for different vehicle types i.e. 1 bus = 1/16 pkw
  - The above needs to be considered carefully since total vehicle numbers will change (reducing overall) emissions so a direct comparison between absolute emissions results based on different vehicle proportions cannot then be made.

Sobol Sensitivity - Conclusion

- At first glance interaction effects are not significant – this is unexpected since it was thought that more buses would change other vehicle behaviour significantly
  - Maybe this will be the case at a more complex junction?
- If there are no second order effects then the model required will be less complex and this will ’cost’ only 1.5% accuracy
- A study based on fixed vehicle numbers is flawed since buses dominate PM2.5 and a ‘replacement factor’ should be considered
- Need to explicitly quantify repeatability and associated variance as a result of randomisation i.e. departure time in the simulation
- 5120 simulations takes around 7 hours

Sensitivity Study – Further Work

- Need to rerun the analysis on a more complex junction that has preferably been validated.
- It may be interesting to see if driving behaviour (however this is characterised) influences contributions from second order effects.
- Should consider simulation period i.e. 24 hrs may be a better measure based on fluctuations in traffic volumes.
  - This does however raise the question of vehicle distribution over the period
- Need to tidy up code and release on github