Improving Safety Calibration in Stochastic Traffic Simulation Models for Freeways by Integration of Crash Data

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C2SMARTER CONNECTED COMMUNITIES WITH SMART MOBILITY TO EQUITABLY REDUCE CONGESTION

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OVERVIEW

Abstract

- **Background:** Safety calibration of Stochastic Traffic Simulation Models (STSMs) often requires detailed vehicle-level data, such as trajectories. However, collecting vehicle trajectories can be expensive and difficult for a wide range of traffic conditions over a long period of time. The STSM calibration when such vehicle-level data is unavailable is a major challenge that prevents STSMs from producing reliable safety related simulation results.
- **Objectives:** This paper proposes a new framework to calibrate STSMs, which combines surrogate safety measure (SSM) and multi-objective stochastic optimization, and it allows the models to be calibrated for both mobility and safety measures simultaneously, even in the absence of vehicle trajectory data.
- **Results:** The calibration results show that the safety performance improvement was particularly significant, exhibiting a major enhancement of 15.4%. Using a different dataset for validation, the calibrated models continued to outperform the uncalibrated and mobility-calibrated models, with a 24% safety measure improvement and a 10% improvement in total loss. The findings were consistent across six random seeds.
- **Conclusions:** It suggests that the calibrated parameters using the proposed method can significantly improve the performance of the simulation model to represent real-world safety conditions, as well as overall conditions including both safety and mobility.

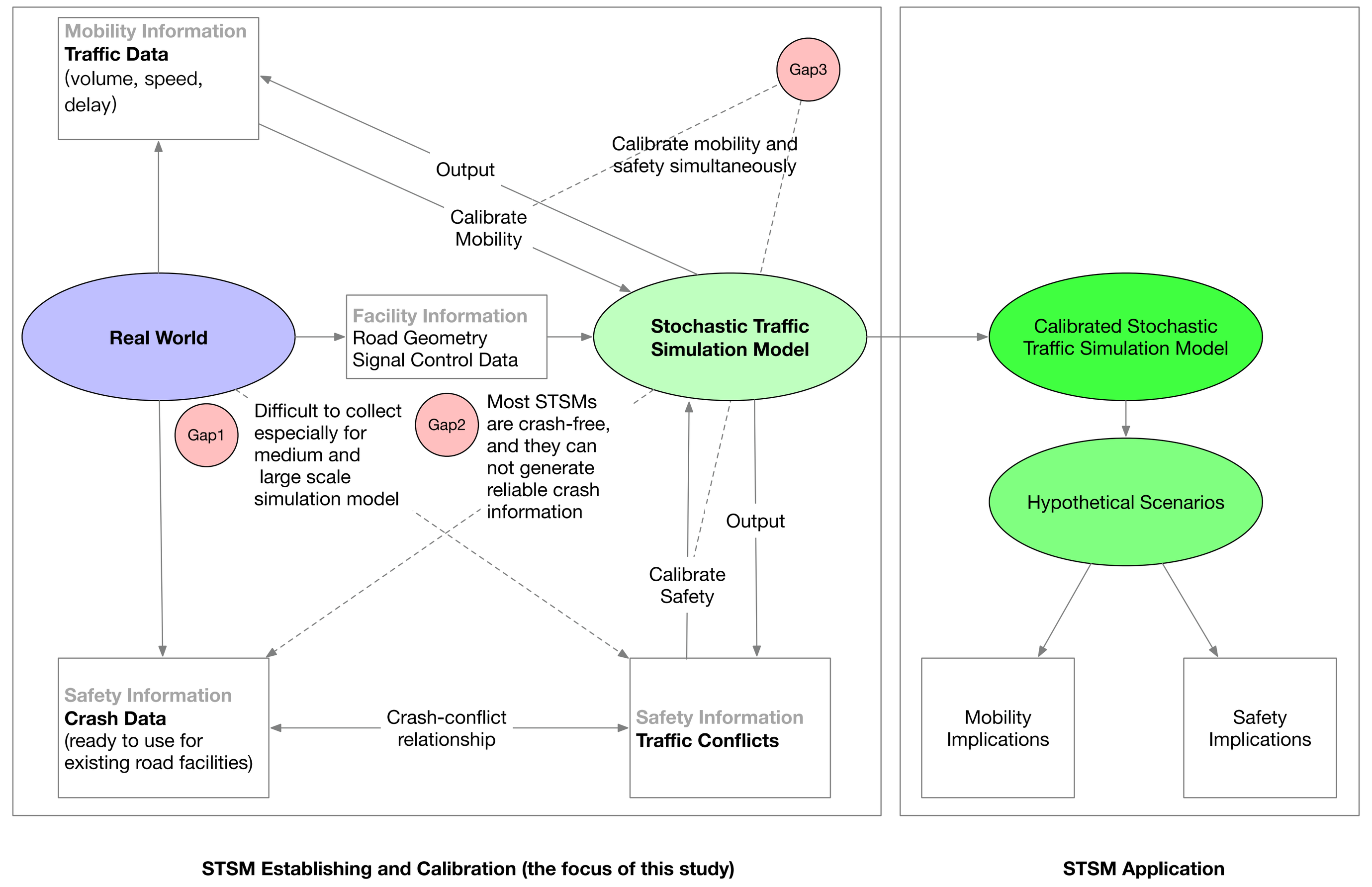
Research Gap 1: It's hard to acquiring accurate and sufficient data required for calibrating Surrogate Safety Measures (SSMs) in medium and large-scale models.

Research Gap 2: It's difficult to generate reliable crash information from STSMs .

Research Gap 3: the simultaneous calibration of mobility and safety .

Key ideas:

- The safety of real world is represented by the frequency of crashes
- The safety of the STSM is represented by SSM, which is generated from the trajectory data
- Link the safety of real world and STSM using SSM-Crash relationship.

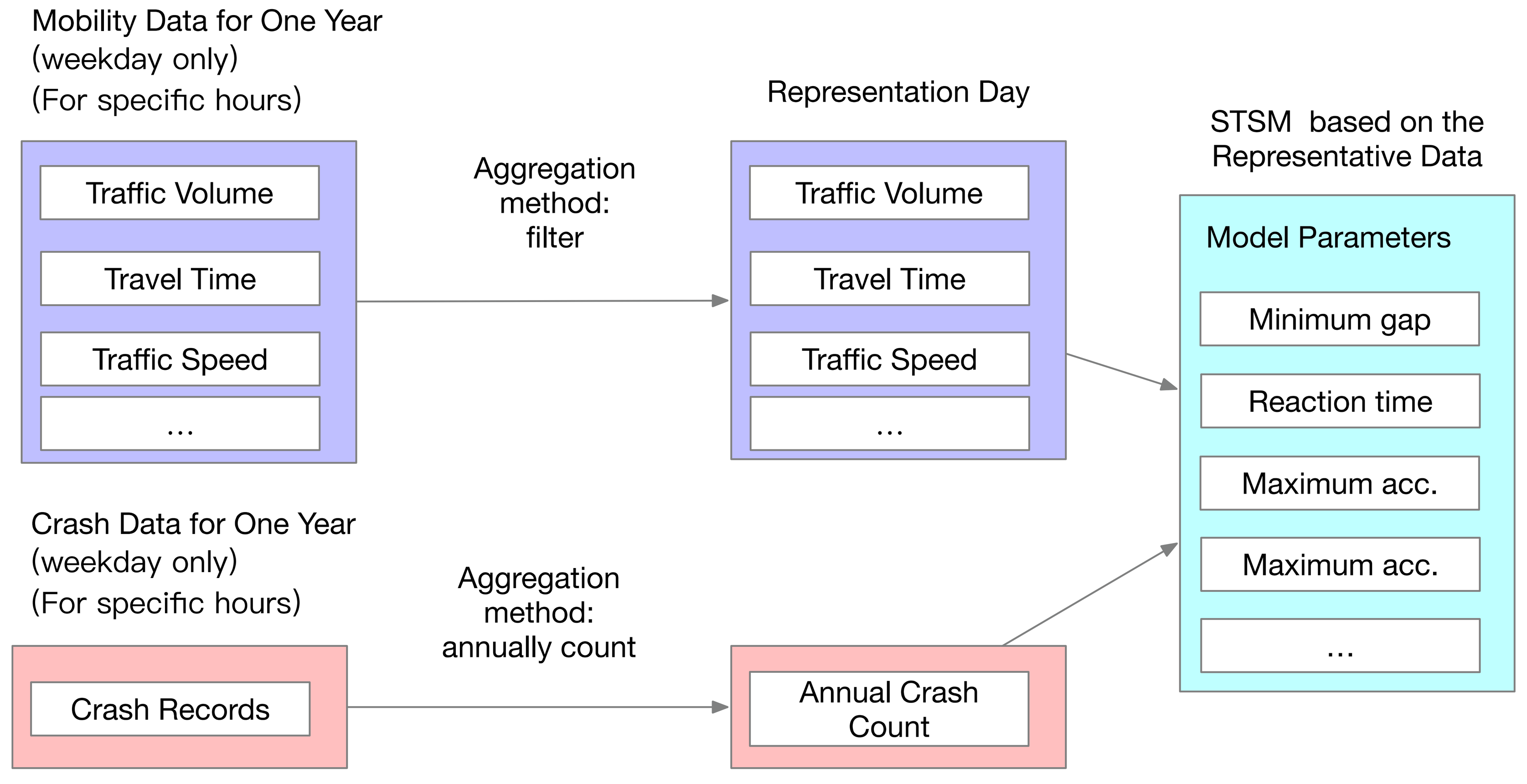


METHODOLOGY – Model Fundamentals

Representation Day
The Federal Highway Administration (FHWA) suggests that it is more feasible to synthesize the data into a representative day, then develop the base simulation model using this day as a reference.

Mobility Data – aggregated by representation day
Mobility measures such as traffic volume, speed, and travel time are calibrated based on the data from the representative day, which is typically a weekday.

Crash Data – aggregated by year
Due to the rarity of crashes, solely using crash data from the representative day isn't feasible. Therefore, we use crash counts spanning over a year. To minimize heterogeneity, we exclude weekend crash data from our dataset.



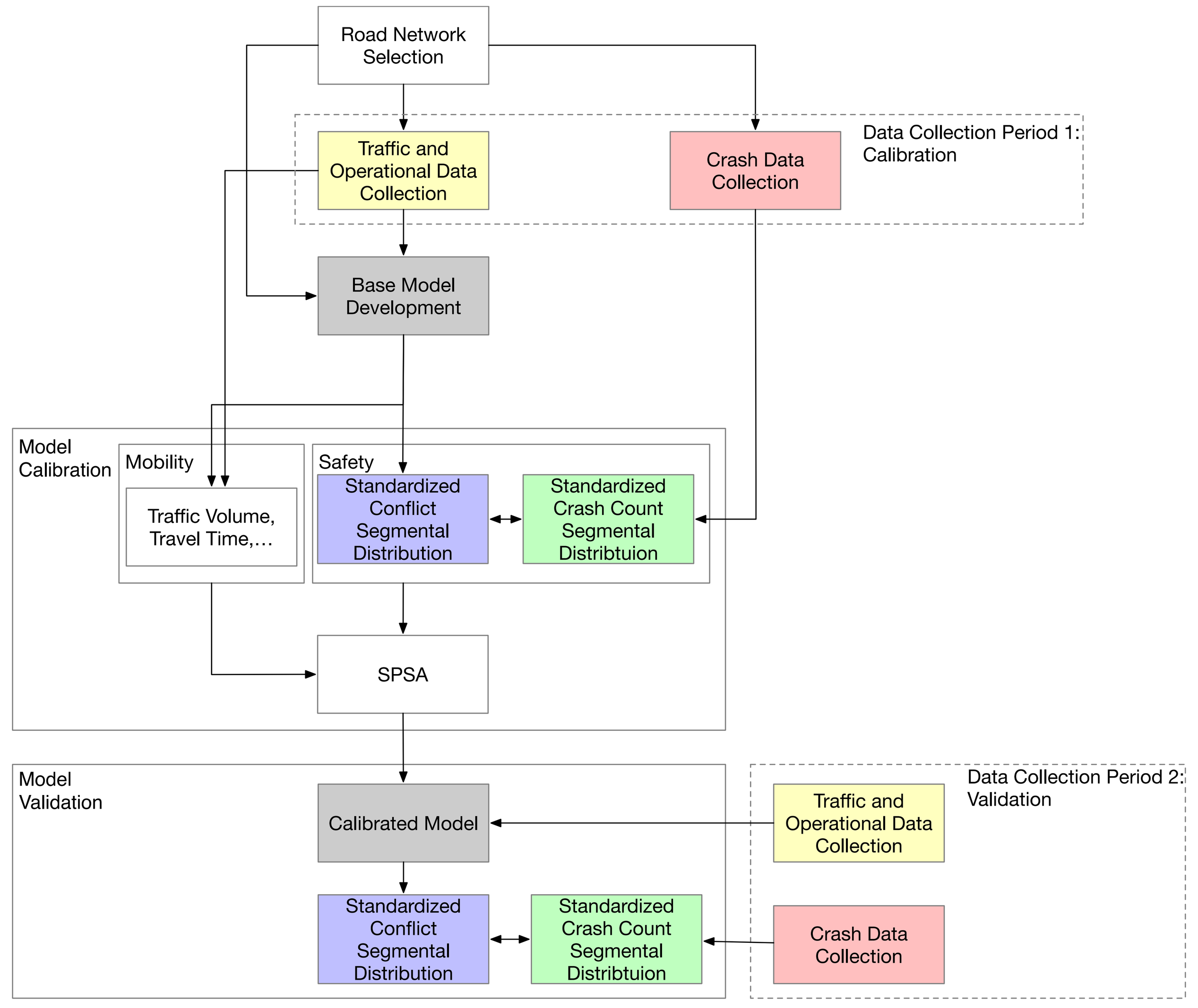
METHODOLOGY – Calibration Framework

Base model Construction:
Base model construction establishes the STSM with initial parameters.
Parameters lists:

- Car tau, Car minigap
- HOV tau, HOV minigap
- Light truck tau, Light truck minigap
- Heavy truck tau, Heavy truck
- Minigap

Multi-objective Calibration :
The multi-objective calibration adjusts model parameters for mobility and safety aspects, using crash count as the primary safety information source

Model Validation :
Model Validation then uses data from a different time period to validate the mobility and safety of the calibrated STSM



The root mean square percentage error (RMSPE) is used as the goodness-of-fit measure for mobility.

$$RMSPE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(\frac{Y_n^{obs} - Y_n^{sim}}{Y_n^{obs}}\right)^2}$$

We use mean absolute error (MAE) as the goodness-of-fit measure for safety

$$MAE = \sum_{i=1}^{N}\left(\left|\left(Y_n^{obs} - Y_n^{sim}\right)\right|/N\right)$$

The Min-Max scaled measure, denoted as x, is computed using the following formula

$$Scaled\ x = \frac{x - min(x)}{max(x) - min(x)} \times 100$$

MAE_{hb} can be calculated as

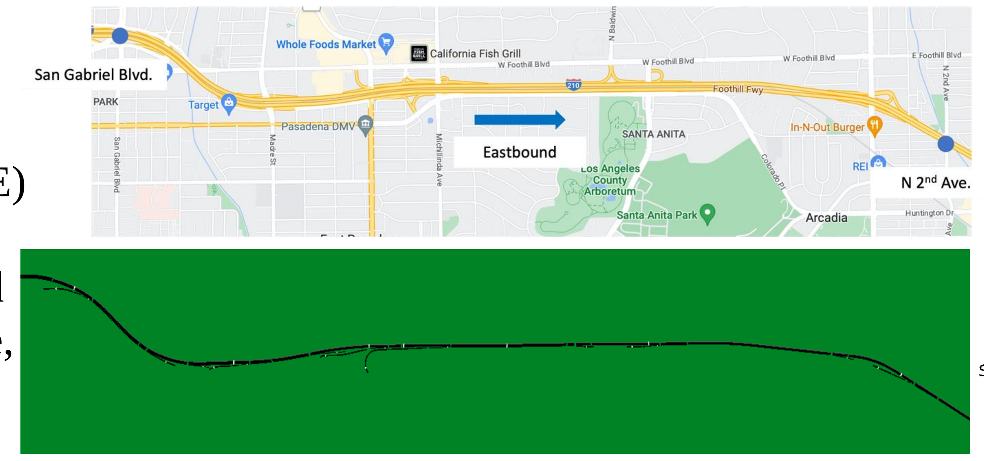
$$MAE_{hb} = \sum_{i=1}^{N}\left(\left|\left(Scaled\_C_n^{obs} - Scaled\_HB_n^{sim}\right)\right|/N\right)$$

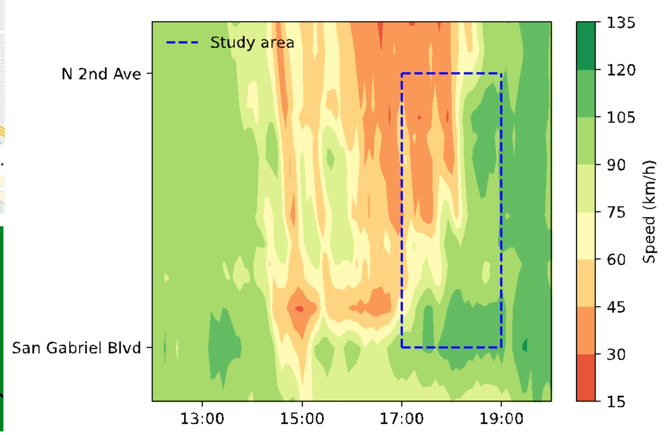
The weighted sum of RMSEP of two mobility measures, traffic volume and travel speed, and MAE of one safety index, hard braking, are used to form the calibration objective function L(θ,I)

$$minL(\theta, I) = \omega_1 \times RMSPE_{vol} + \omega_2 \times RMSPE_{sp} + \omega_3 \times MAE_{hb}$$

CASE STUDY - Networks

This study uses a specific section of the Interstate 210 Eastbound (I210-E) between San Gabriel Boulevard and N 2nd Avenue, up to 6.6 km.

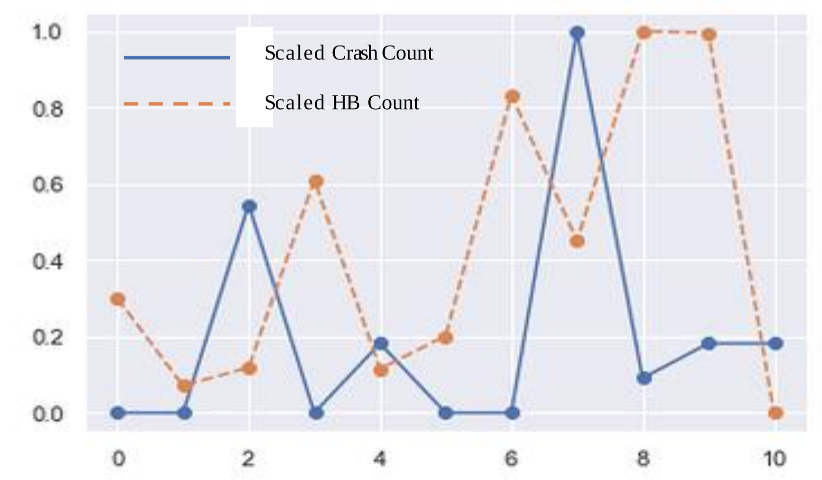




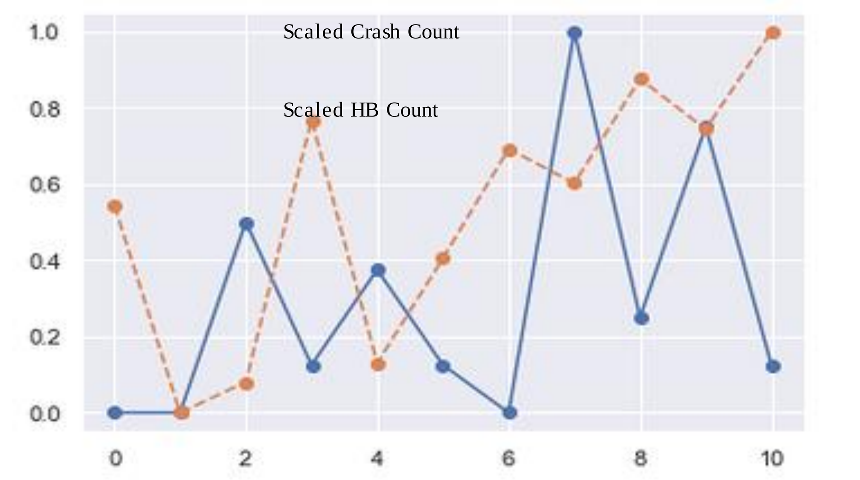
CASE STUDY - Results

Using calibration data set

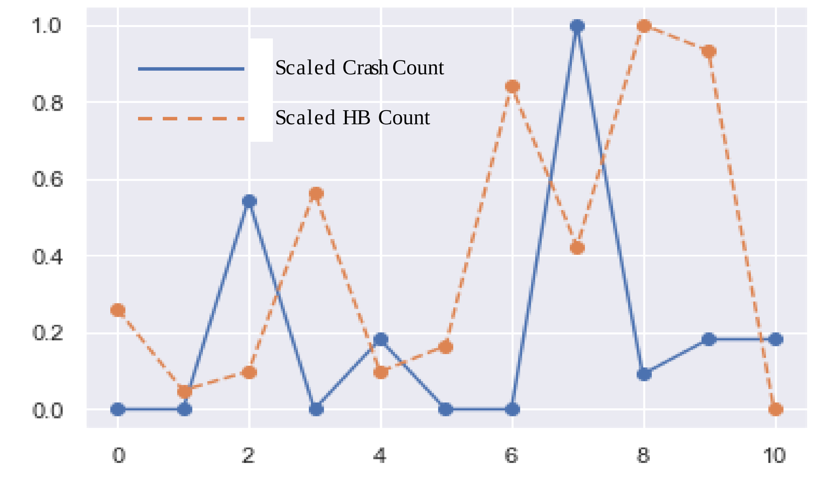
Using validation data set



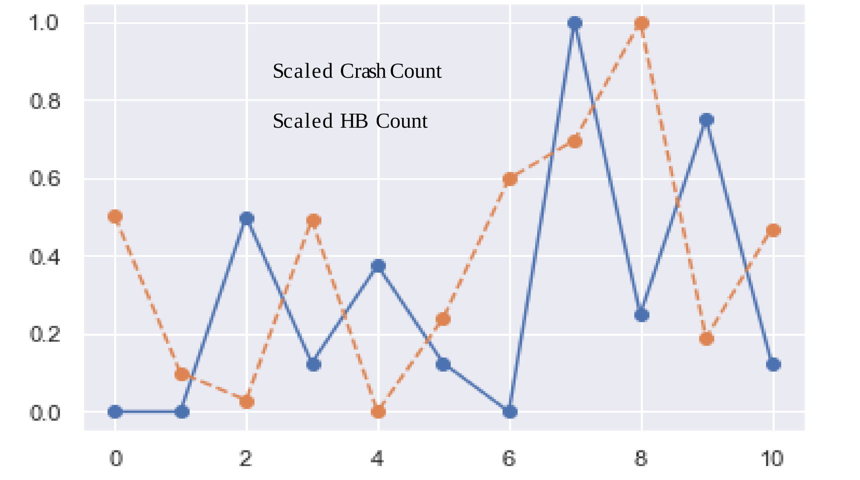
(a) uncalibrated model(17:00-18:00), $_{hb}$ = 0.45, (,) = 0.22



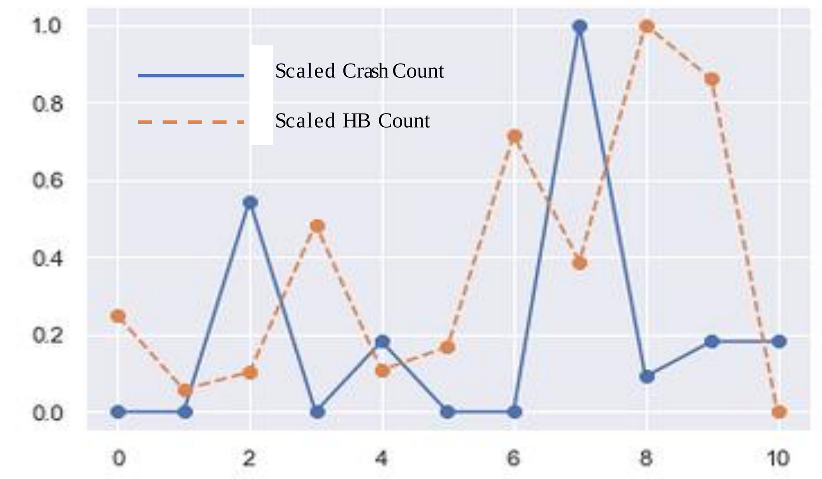
(d) uncalibrated model(18:00-19:00), $_{hb}$ = 0.43 , (,) = 0.22



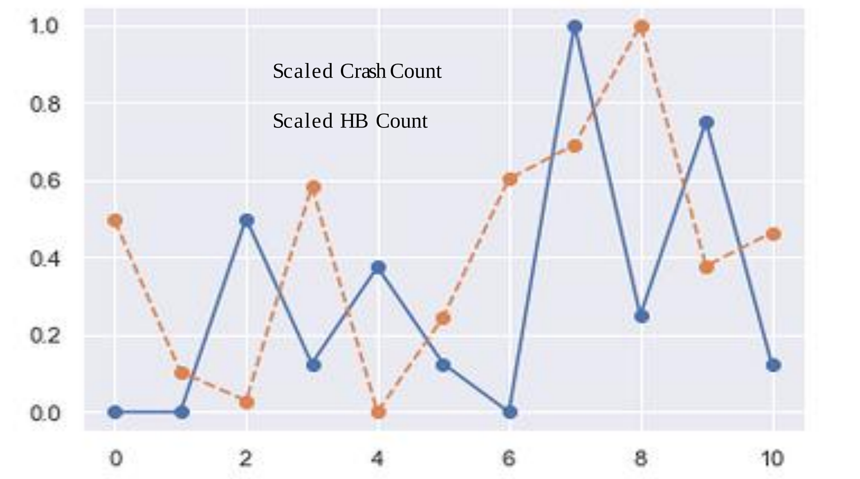
(b) Model calibrated only for mobility (17:00-18:00) , $_{hb}$ = 0.44, (,) = 0.22



(e) Mobility calibrated model (18:00-19:00) , $_{hb}$ = 0.41, (,) = 0.20



(c) Model calibrated for both mobility and safety (17:00-18:00), $_{hb}$ = 0.39, (,) = 0.20



(f) Mobility and Safety calibrated model (18:00-19:00), $_{hb}$ = 0.40, (,) = 0.20

The model calibrated for both mobility and safety stood out for having the smallest MAE_{hb} and the lowest loss value.

TAKE AWAYS

- This study introduces a novel framework for calibrating Stochastic Traffic Simulation Models (STSMs), incorporating Surrogate Safety Measure (SSM) and multi-objective stochastic optimization. This unique approach addresses the challenge of trajectory data scarcity and non-simultaneous calibration of operational and safety measures.
- The research highlights the critical interplay between mobility and safety. While mobility calibration led to a slight safety improvement (by 2.5%), a dedicated calibration targeting both mobility and safety yields more profound results.