SOON CHUN HYANG UNIVERSITY

2024 SAIL Seminar

# An integrated car-following and lane changing vehicle trajectory prediction algorithm based on a deep neural network

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# 1. Introduction

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- Development of automated vehicle technology

↪ Prediction → Essential module

<Key factor>

Accurate vehicle trajectory prediction → Safety and control efficiency of automated driving systems

- Many SOTA control models use surrounding vehicle trajectory information

Inaccurate vehicle trajectory information → Unsafety and control inefficiency of automated driving systems

# 1. Introduction

- Vehicle trajectory prediction
  - Car following movement
  - Lane change movement

- Lane change : vehicle moving from one lane to a nearby lane

- Car following : vehicle continuously following the leading vehicle in the same lane

# 1. Introduction

- Methodology differences
  - Model based methods
  - Data-driven methods

- Model based methods : Trajectory prediction presumed model from traffic flow theory perspective

- Data-driven methods : Data-driven fashion for using neural networks

# 1. Introduction

< Model based methods >

- Great interpretability to explain certain traffic phenomenons

IDM (intelligent driver model)

- Car following prediction model
- Traffic flow simulation

MOBIL

- Lane change prediction model
- Lane-specific macroscopic quantities to model different lane change traffic condition

However, prediction errors when a model mismatch occurs and driver behavior changes drastically

# 1. Introduction

< Data-driven methods >

- LSTM, RNN, GAN ···
- Lane change, Car following as an independent process
- Widely analyzed traffic flow areas, the dependencies between two movements are significant

Car following movement → cause instability in traffic flow

lane change interval variation

Lane change movement → car following distance and speed difference

⬇

Negatively affects entire traffic flow

# 1. Introduction

- Lane change + Car following
- Integrated vehicle trajectory prediction model (lane change choice + vehicle trajectroy)

  ↪ Deep long short term memory neural network with a switch structure

< Switch structure >

- Lane change prediction output

  ↪ Used feature → describe car following relationship

- Additional temporal depths → TCN

# 2. Mathematical formulation of integrated two-dimensional vehicle trajectory prediction

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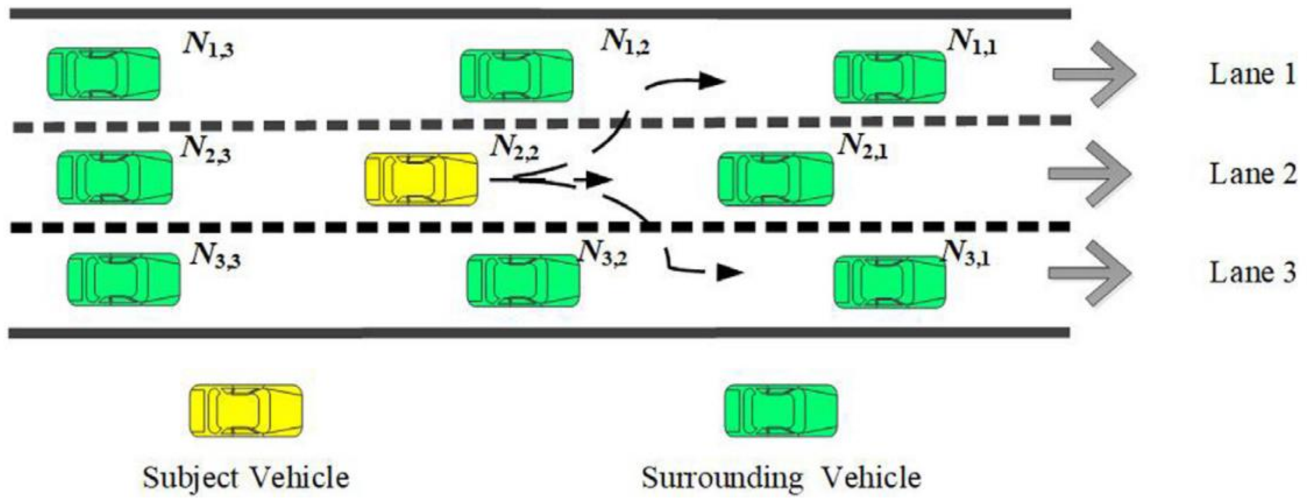



- 9 vehicles
- $N_{i,j}$ : $i$ (lane), $j$ (preceding · following vehicle)
- n : prediction horizon
- m : memory horizon

- Time t ~ t-n
- Predict future portfolio of SV

## 2. Mathematical formulation of integrated two-dimensional vehicle trajectory prediction

< Input data >

$\Delta P_t$ : The set of position information at time $t$

$\Delta P_t = [Pt-m, Pt-m+1, \ldots, Pt]$

$V_t$ : The set of speed information at time $t$

$V_t = [Vt-m, Vt-m+1, \ldots, Vt]$

$A_t$ : The set of acceleration information at time $t$

$A_t = [At-m, At-m+1, \ldots, At]$

$\Delta V_t$ : The set of speed difference information at time $t$

$\Delta V_t = [\Delta Vt-m, \Delta Vt-m+1, \ldots, \Delta Vt]$

$S_t = [\, \Delta P_t, V_t, A_t, \Delta V_t \,]$

## 2. Mathematical formulation of integrated two-dimensional vehicle trajectory prediction

$$\overrightarrow{\boldsymbol{\phi}}_{\boldsymbol{t}} = H(\Delta\mathbb{P}_t, \mathbb{V}_t, \Delta\mathbb{V}_t, \mathbb{A}_t)$$

- H : lane change prediction function
- {-1, 0, 1} | LLC : -1 / LK : 0 / RLC : 1

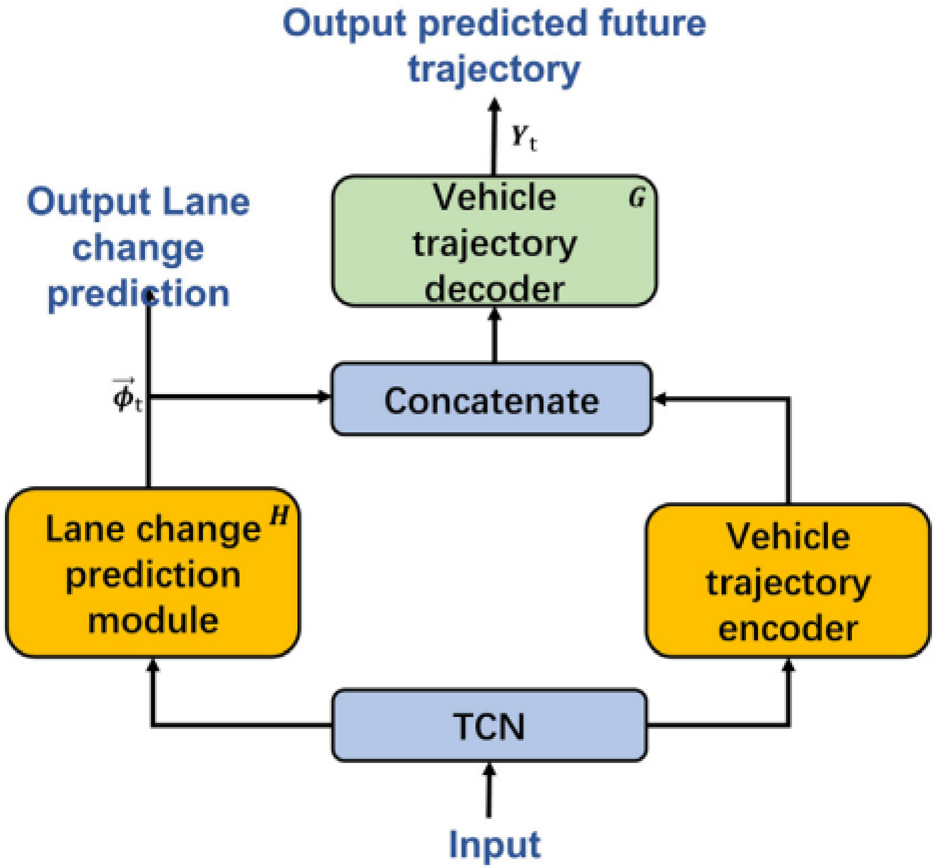
$$Y_t = G([\overrightarrow{\phi}_t\ S_t])$$

- G : Longitudinal trajectory prediction function
- Predicted position of the vehicle at time t

# 3. Integrated two-dimensional vehicle trajectory prediction model

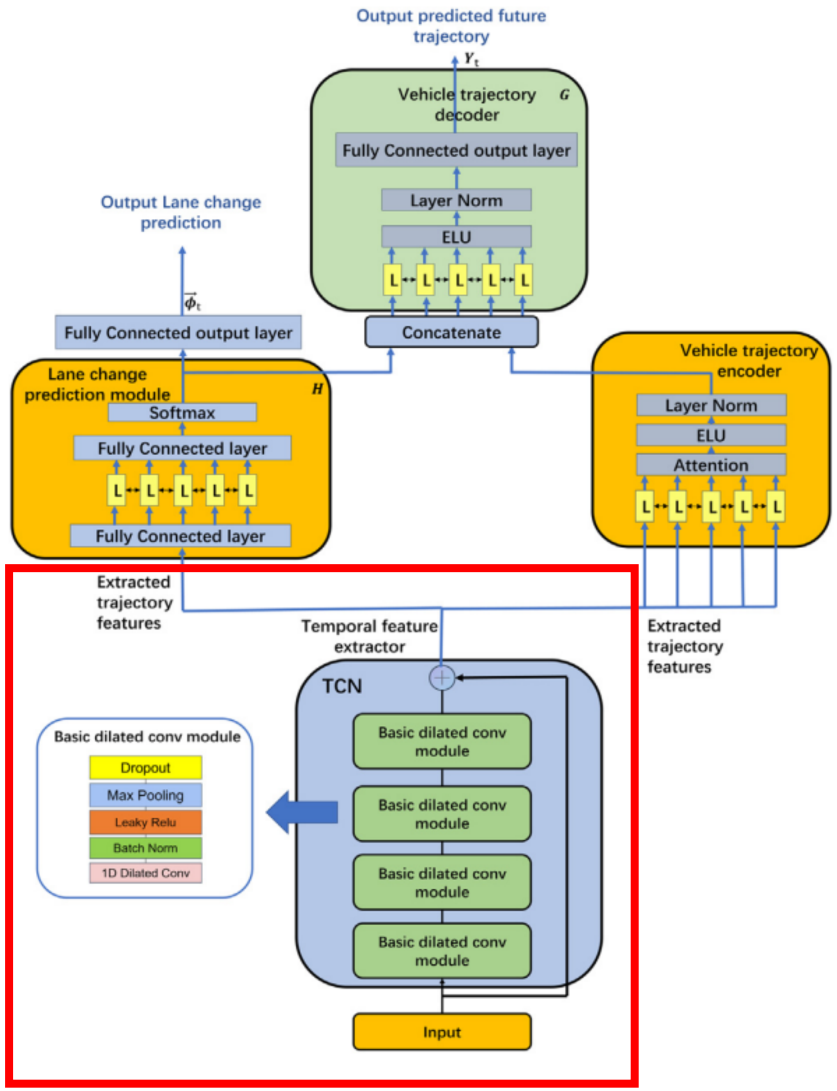
# 3. Integrated two-dimensional vehicle trajectory prediction model

a. Model structure



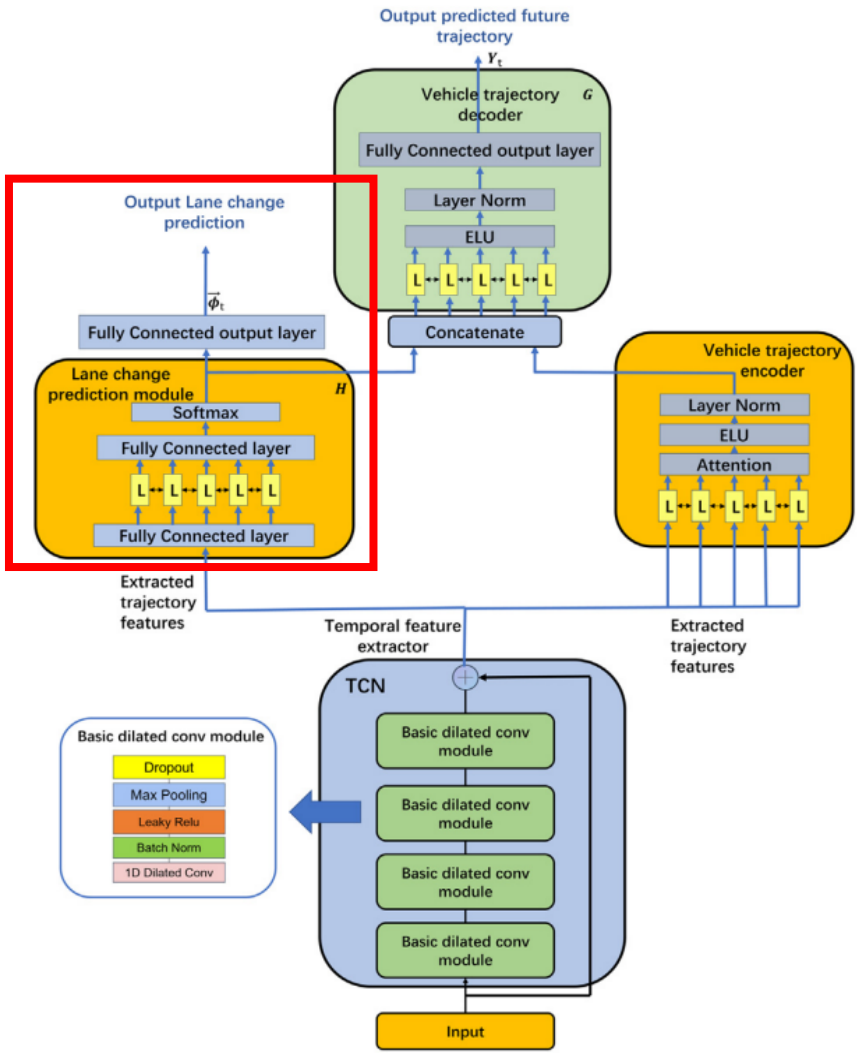
# 3. Integrated two-dimensional vehicle trajectory prediction model

b. TCN




TCN

- feature extraction (time domain extraction)
- trajectory features

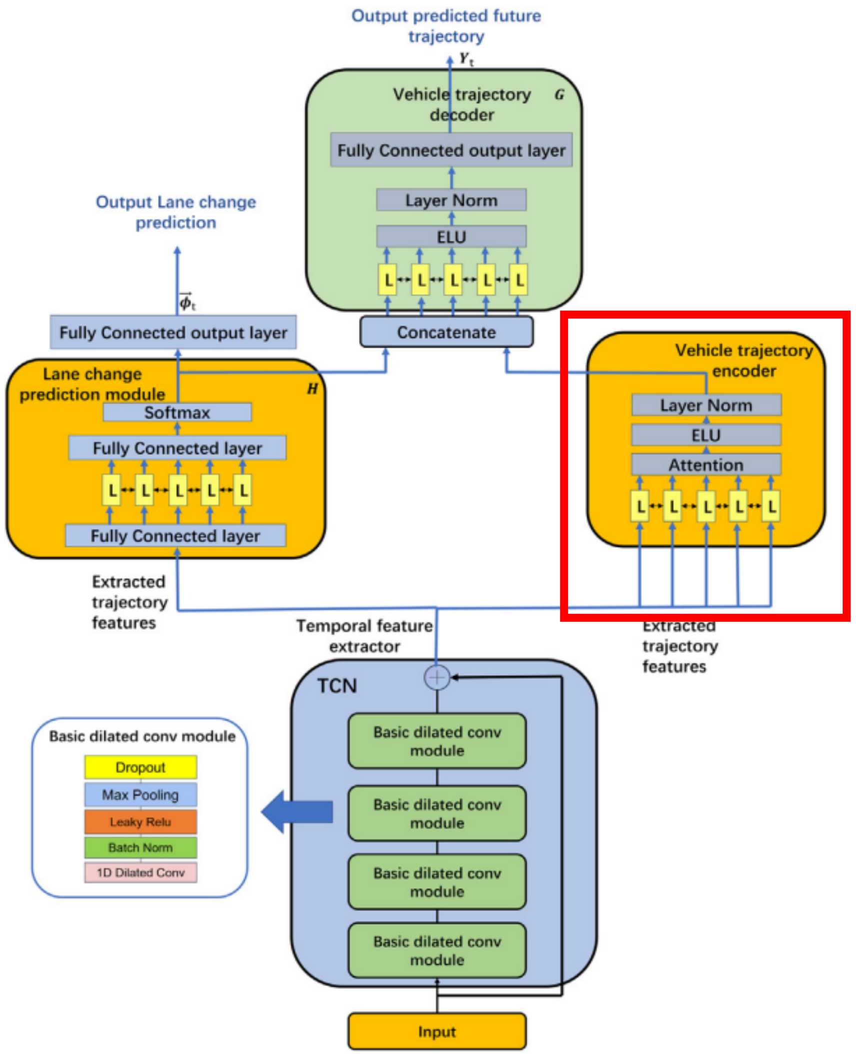



Lane change prediction module

- Bi-LSTM, FC layer
- Lane change prediction output
- Combine results with other parts of the model

# 3. Integrated two-dimensional vehicle trajectory prediction model

## d. Vehicle trajectory encoder

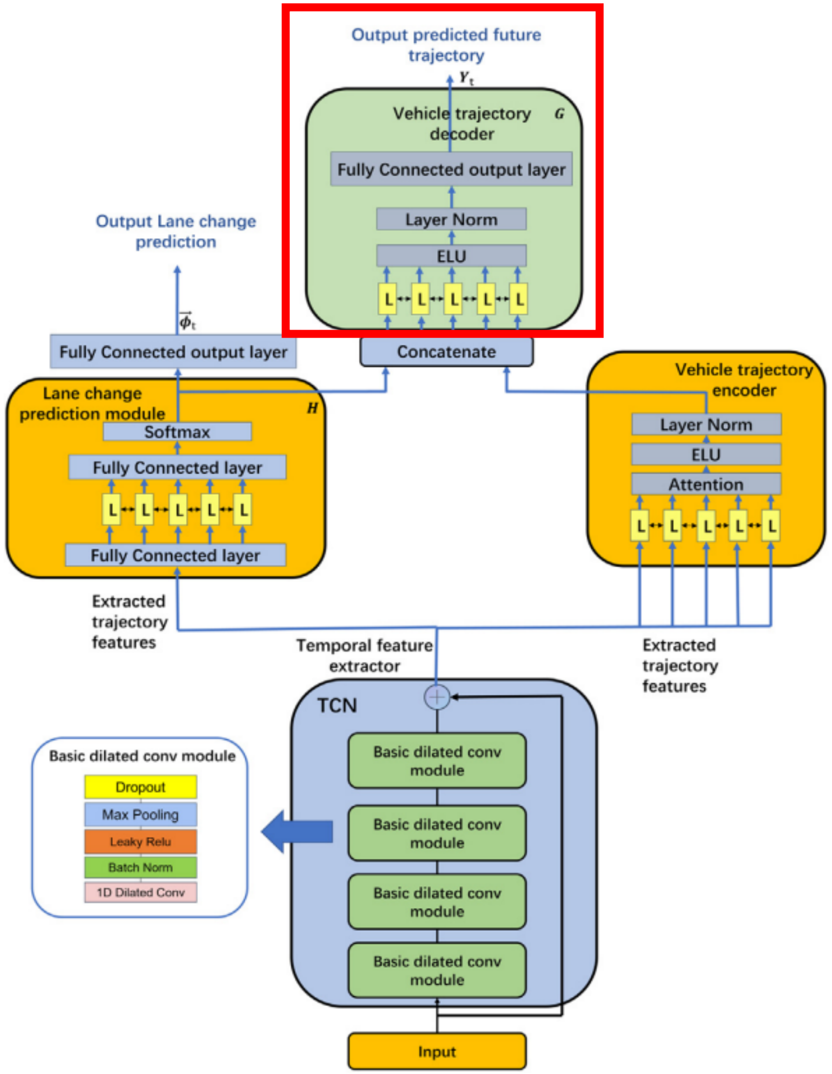



Vehicle trajectory encoder

- Bi-LSTM, Attention, ELU
- Extract more sophisticated trajectory features

# 3. Integrated two-dimensional vehicle trajectory prediction model

e. Vehicle trajectory decoder




Vehicle trajectory decoder

- Bi-LSTM, Attention, ELU, FC layer
- Lane change + Vehicle trajectory
- Predict the future trajectory

# 3. Integrated two-dimensional vehicle trajectory prediction model

## f. Model training

$$L = \frac{1}{n}\sum_{i=0}^{n}(Y_i - \hat{Y}_i)^2 - \sum_{k=0}^{2} y_k log(\hat{y}_k)$$

MSE

Cross Entropy

$Y_i$ Actual position

$\hat{Y}_i$ Predicted position

$y_k$ Actual movement type

$\hat{y}_k$ Predicted movement type

# 4. Experiments and results

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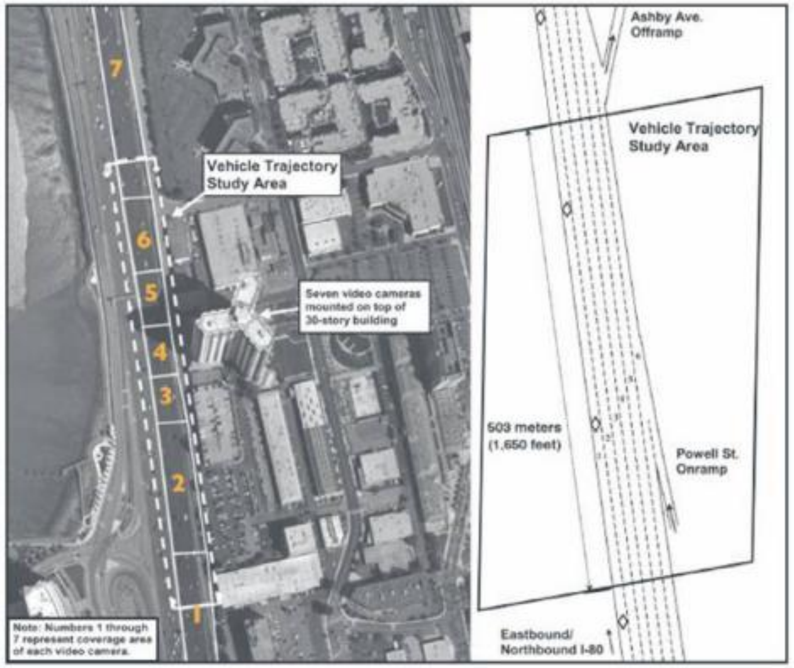
## a. Data description




- NGSIM Dataset
- Train : 2250 / Test : 250

# 4. Experiments and results

b. Quantitative evaluation metrics

- MAE
- RMSE
- F1 score
- Precision
- Recall
- Accuracy

$$MAE = \frac{\sum_{i=0}^{K} |Y_i - \widehat{Y_i}|}{K}$$

$$RMSE = \sqrt{\frac{\sum_{i=0}^{K} (Y_i - \widehat{Y_i})^2}{K}}$$

$$F1 = 2 \times \frac{precision \times recall}{precision + recall}$$

# 4. Experiments and results

c. Model prediction performance comparison

※ ITPM (Integrated Trajectory Prediction Model)

Model general performance experiment result.

| Model | MAE | RMSE | Accuracy | F1 |
|---|---|---|---|---|
| ITPM | **2.11** | **5.67** | **0.8789** | **0.8372** |
| ITPM without TCN layer | 2.79 | 6.23 | 0.8220 | 0.8011 |
| ITPM without attention layer | 2.63 | 6.01 | 0.8720 | 0.8241 |
| ITPM BiLSTM feature extractor | 2.59 | 6.14 | 0.8512 | 0.8193 |
| Baseline BiLSTM [46] | 3.67 | 8.36 | N/A | N/A |
| Baseline LSTM [45] | 4.21 | 9.37 | N/A | N/A |
| Baseline IDM+MOBIL [14,19] | 6.23 | 12.72 | 0.64879 | 0.6331 |
| ConvLSTM [47] | 3.21 | 6.77 | N/A | N/A |

- TCN O > TCN X
- Attention layer O > Attention layer X
- TCN > Bi-LSTM
- ITPM > IDM + MOBIL

# 4. Experiments and results

c. Model prediction performance comparison

Model prediction efficiency experiment result. ※ ITPM (Integrated Trajectory Prediction Model)

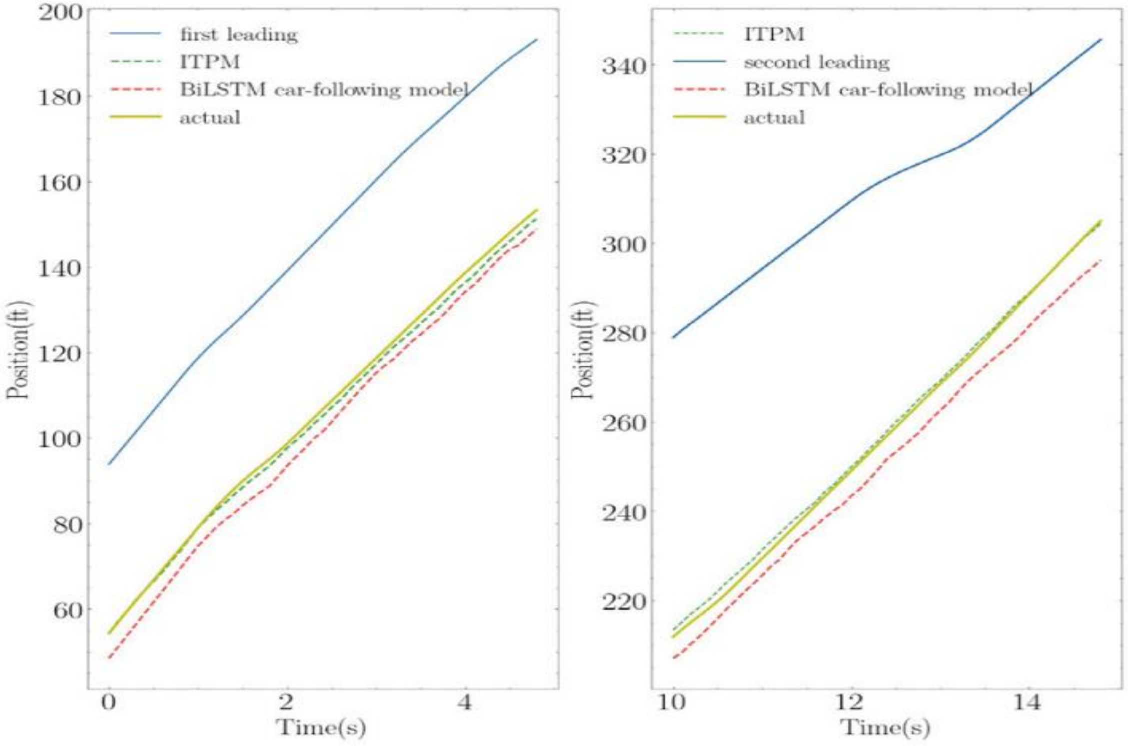
| Model | Parameters | Inference time |
|---|---|---|
| ITPM | 861084 | 21.7 ms |
| ITPM without TCN layer | 770784 | 17.8 ms |
| ITPM BiLSTM feature extractor | 832198 | 22.8 ms |
| ITPM without attention layer | 843751 | 19.5 ms |
| Baseline BiLSTM [46] | 323756 | 8.7 ms |
| Baseline LSTM [45] | 157480 | 3.7 ms |
| Baseline IDM+MOBIL [14,19] | N/A | N/A |
| ConvLSTM [47] | 467338 | 14.6 ms |

- Complexity of switch structure → more parameter and inference time
- Less than 30 ms

  ↪ Still adequate for automated driving and other intelligent system transportation applications

# 4. Experiments and results

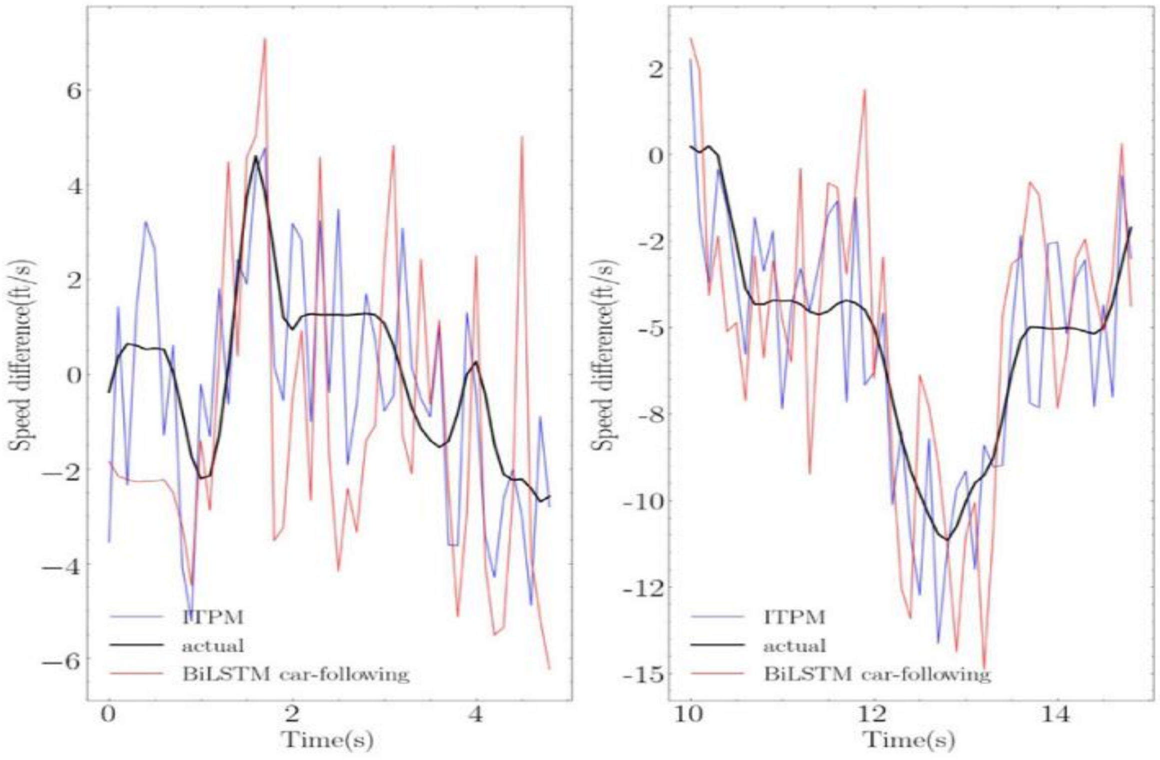
## c. Model prediction performance comparison




- Memory horizon, prediction horizon : 3s
- First · second leading = preceding vehicle
- Change in distance over time
- ITPM > Bi-LSTM

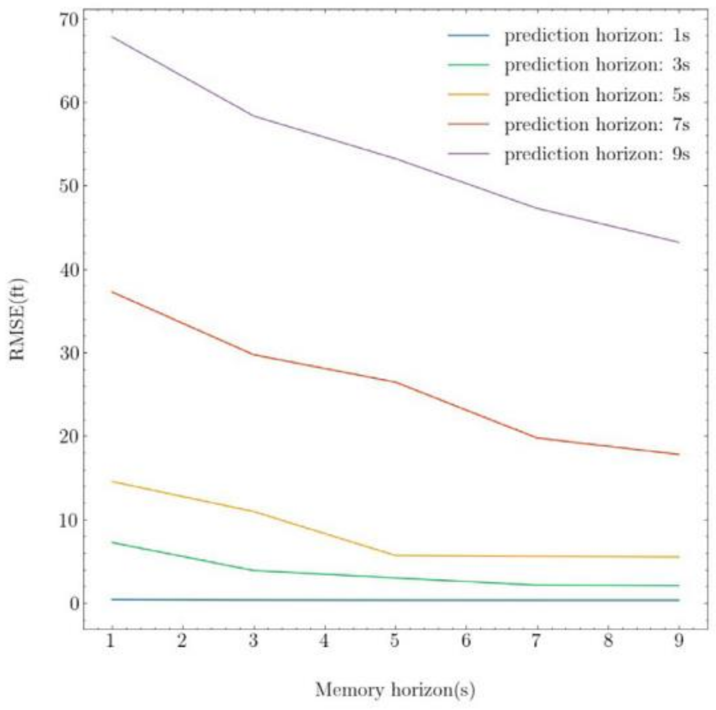
# 4. Experiments and results

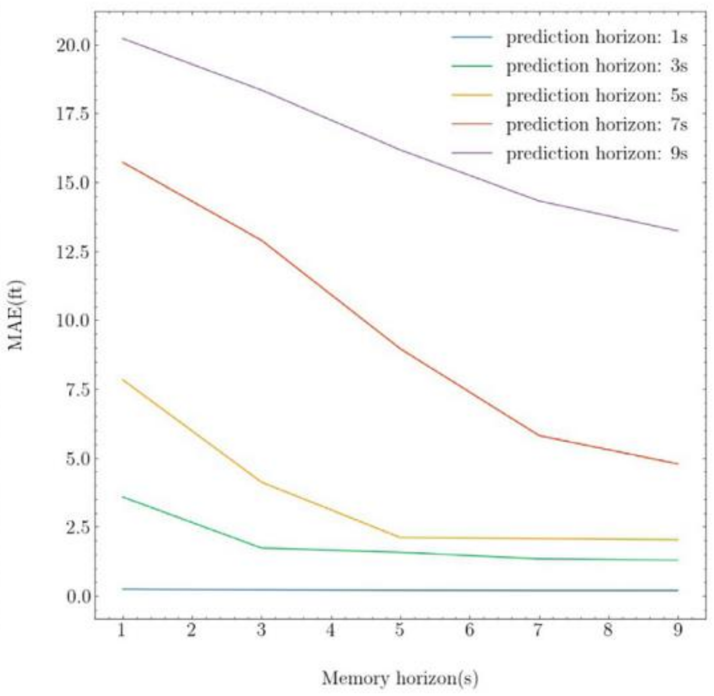
## c. Model prediction performance comparison




- Change in speed over time
- Small and big fluctuations
- ITPM > Bi-LSTM
- Smoother predictions

# 4. Experiments and results
## d. Model performance sensitivity analysis




- Memory horizon ↑
- Prediction horizon ↓
- Performance degradation when increased by more than prediction horizon 5s

# 5. Conclusions

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Lane change
Car following
] Two dimensional Trajectory prediction model

TCN + Bi-LSTM + Attention mechanism = switch structure model

1. Model comparison results → Better performance
2. Prediction / memory horizon sensitivity analysis → Give practitioners guidance

Effective short term and long term trajectory prediction model

# 6. How to Apply

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- 입력 변수에 대한 수식 참조
- 모델 프레임 워크
- 교통 모델에 대한 비교군
- Car following / Lane Keeping

# Thanks

☺