A Modified Social Force Model (SFM) for Pedestrian Behavior in the Presence of Autonomous Vehicles (AVs)

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MOTIVATION & RESEARCH OBJECTIVE

Are There Significant Behavioral Changes Of Pedestrians In The Way They Interact With Vehicles At A Crossing When A Portion Of The Vehicles Is Autonomous?

- **How will pedestrians understand AV's intension?**
- **How will pedestrians predict AV's action?**
- **How pedestrian will interact with AV?**
- **How to decide to go or wait?**

Develop a theory-based approach to model pedestrian behavior in a signalized crosswalk for AV based on the original social force model (SFM)

Simulate the pedestrian behavior based on SFM at a signalized crosswalk where only driverless AVs are on the road.

Propose a modified social force model to understand pedestrian behavior in a signalized crosswalk where only AVs are on the road.

Compare the pedestrian behavior in the presence of human-driven and driverless vehicles within a simulated environment at a signalized crosswalk

The modified SFM is utilized to simulate pedestrian behavior in a simulation environment called VADERE

MODELING FRAMEWORK (Social Force Model)

$$\overrightarrow{F_a}(t) = \textit{All the personal desire related driving Force} + \textit{all other pedestrian related repulsive Force} + \textit{all other stationary object related repulsive Force} + \textit{all the attraction related interaction force}$$

The force from the crosswalk boundary $\overrightarrow{F_c}$

$$=: \begin{cases} \overrightarrow{F^r_{\mathrm{B}\alpha}} = A^r_{\mathrm{B}} \exp\left(-B^r_{\mathrm{B}} \left|\left|\overrightarrow{P_\alpha} - \overrightarrow{P_B}\right|\right|\right) \overrightarrow{n_{B\alpha}}, & if\ ped\ \alpha \text{ inside the crosswalk} \\ \overrightarrow{F^a_{\mathrm{B}\alpha}} = A^a_{\mathrm{B}} \exp\left(-B^a_{\mathrm{B}} \left|\left|\overrightarrow{P_\alpha} - \overrightarrow{P_B}\right|\right|\right) \overrightarrow{n_{\alpha B}}, & otherwise \end{cases}$$

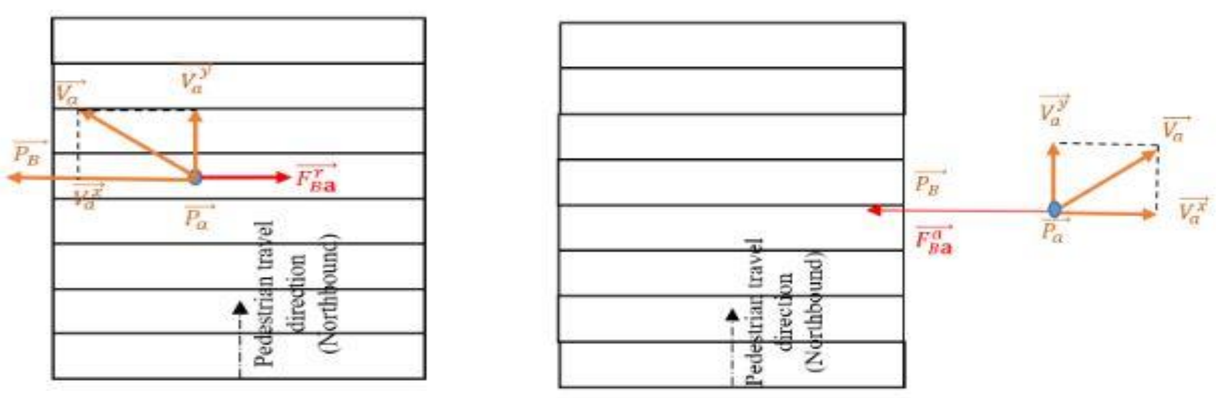


Figure 1. Repulsive and attractive forces from crosswalk boundary

MODELING FRAMEWORK (Social Force Model for AV)

The repulsive force from AV

$$F^{\alpha z}_{rep(av)}(\overrightarrow{r_{\alpha z}}) := -\nabla \overrightarrow{r_{\alpha z}} K_{\alpha z}(\overrightarrow{||r_{\alpha z}||})$$

Here, $K_{\alpha z}(\overrightarrow{||r_{\alpha z}||})$ is the repulsive potential, and $\nabla \overrightarrow{r_{\alpha z}}$ is the divergent behavior of the pedestrian as opposed to the location of the AV.

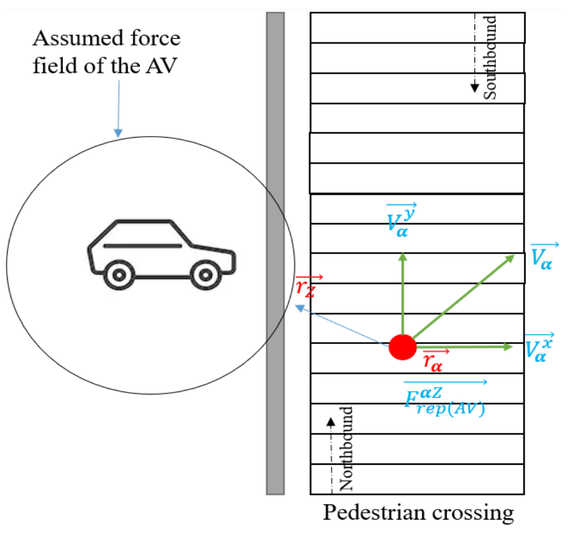


Figure 2. Repulsive Force ($F^{\alpha z}_{rep(av)}$) of the pedestrian due to AV in a signalized crosswalk

Modified Social Force Model (SFM) for Autonomous Vehicle (AV)

$$F^{AV}_a(t) = F_p + F_c + F^{\alpha\beta}_{repv} + F^{\alpha p}_{repv} + F^{\alpha i}_{at} + F^{\alpha z}_{rep(av)}$$

SIMULATION EXPERIMENTS

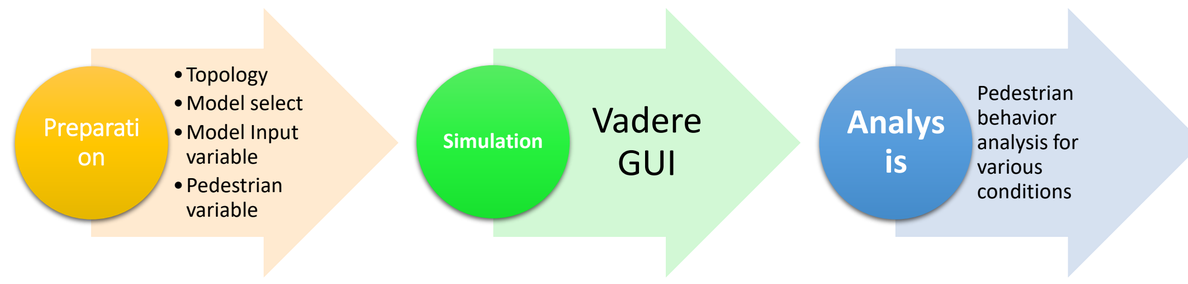


Table 1. Simulation parameter and values

Simulation variables	Selected values
Number of pedestrians (Southbound)	15
Number of pedestrians (Northbound)	10
Obstacle repulsion strength	0.1 ~ 0.6
Pedestrian density weight	2.1
Obstacle density weight	10

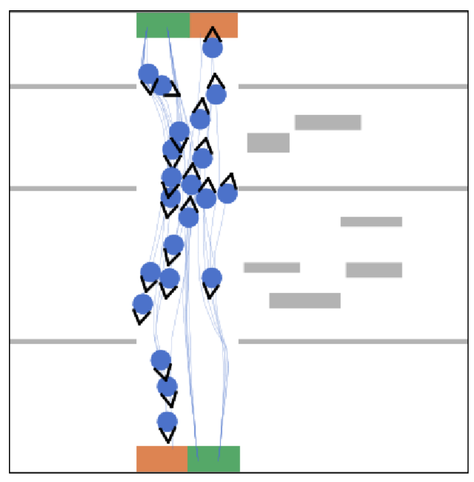
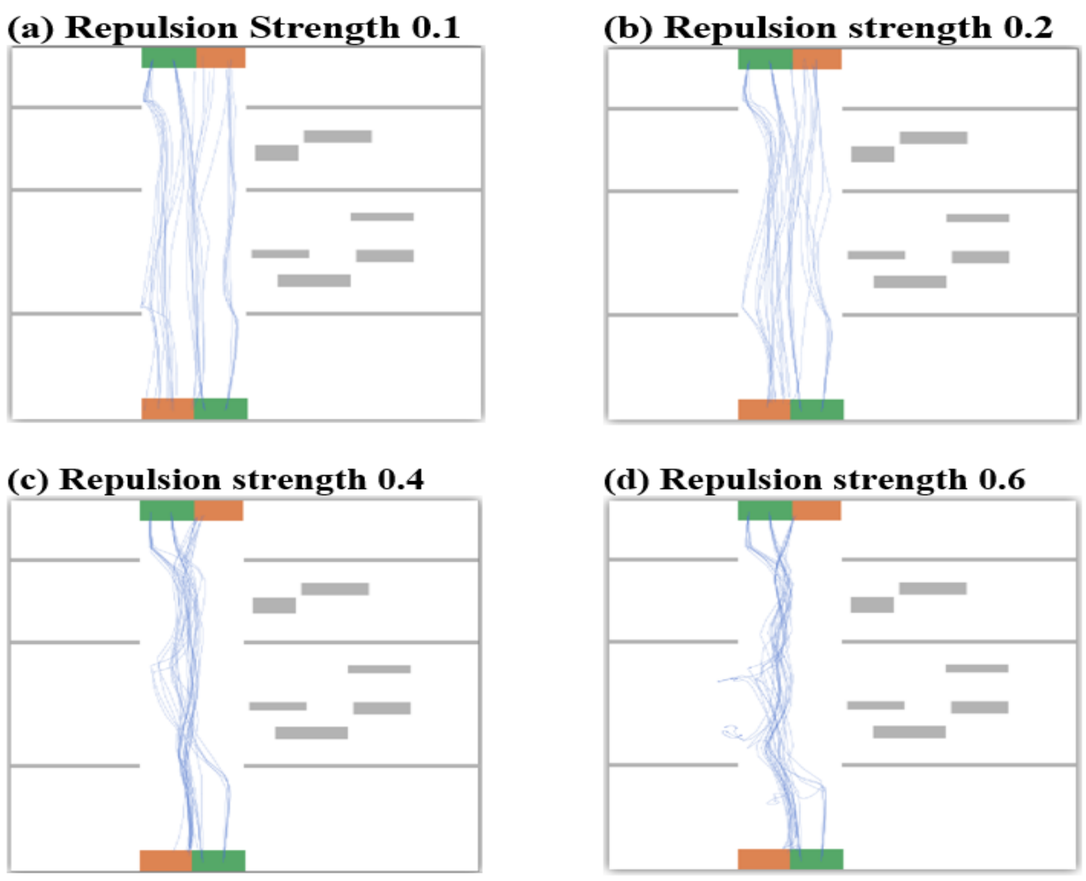


Figure 3. VADERE programmable interface

SIMULATION RESULTS



DISCUSSION

Chaotic pedestrian movement indicates longer paths for pedestrians and causes longer crossing times

Longer pedestrian crossing times can impact traffic operations, cause further delays, and require adjustment of signal patterns at signalized crosswalks and intersections.

The presence of AV on the road may not impact all the pedestrians at the crosswalk; however, one pedestrian's chaotic crossing behavior will ultimately force the other pedestrian to be crossing the road chaotically.

The pedestrian inconvenience could lead to them choosing other modes of transportation, impacting overall transportation planning. This may require adjustments in traffic operations for mixed driving situations.

FUTURE WORK

- **This model is intended to work for signalized crosswalks only, and new models or adjustments are needed to model an unmarked crosswalk.**
- **Various assumptions were made for the simulation, such as no right or left-turning vehicle in that intersection.**