Affordance-based agent model for road traffic simulation

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Introduction

- General Approach: In urban areas with high traffic density, roads are often divided into lanes and drivers must respect road space divisions.
- Static organization is not always the most efficient.
- Multi-agent systems (MAS) provide a suitable solution for traffic simulation problems, traffic management and traffic signal control
- Existing models:
  - do not consider maneuvers between vehicles or dynamic lane allocation
  - are developed for one particular type of driver
  - cannot be applied to other situations such as traffic jams
- Proposed model creates Ego-centered representation of environment where spatial relations are generally directly related to the agent (reference system: left, right, forward or backward)
- Proposed model is based on the theory of Affordances.

Affordance Based Model

- An **affordance** is a quality of an object or an environment that allows a situational agent to perform an action.
- Each agent perceives the environment through a set of vectors and scalar fields that are represented in its local space (**ego-centered location-space**) and proposes an affordance-based driver agent model for space occupation.
- It builds a set of intervals representing the free space around it and depicts these different intervals in an ego-centered representation.
- Analyze these intervals and deduce affordances
- The agent uses a fitness function to evaluate its affordances and select the most suitable one.

Non-normative Behavior

- **Non-normative behavior** means that the driver does not fully respect traffic rules
- Real driver behavior does is often non-normative.
- Non-normative is more efficient, such as in terms of travel time (sometimes at a group level)

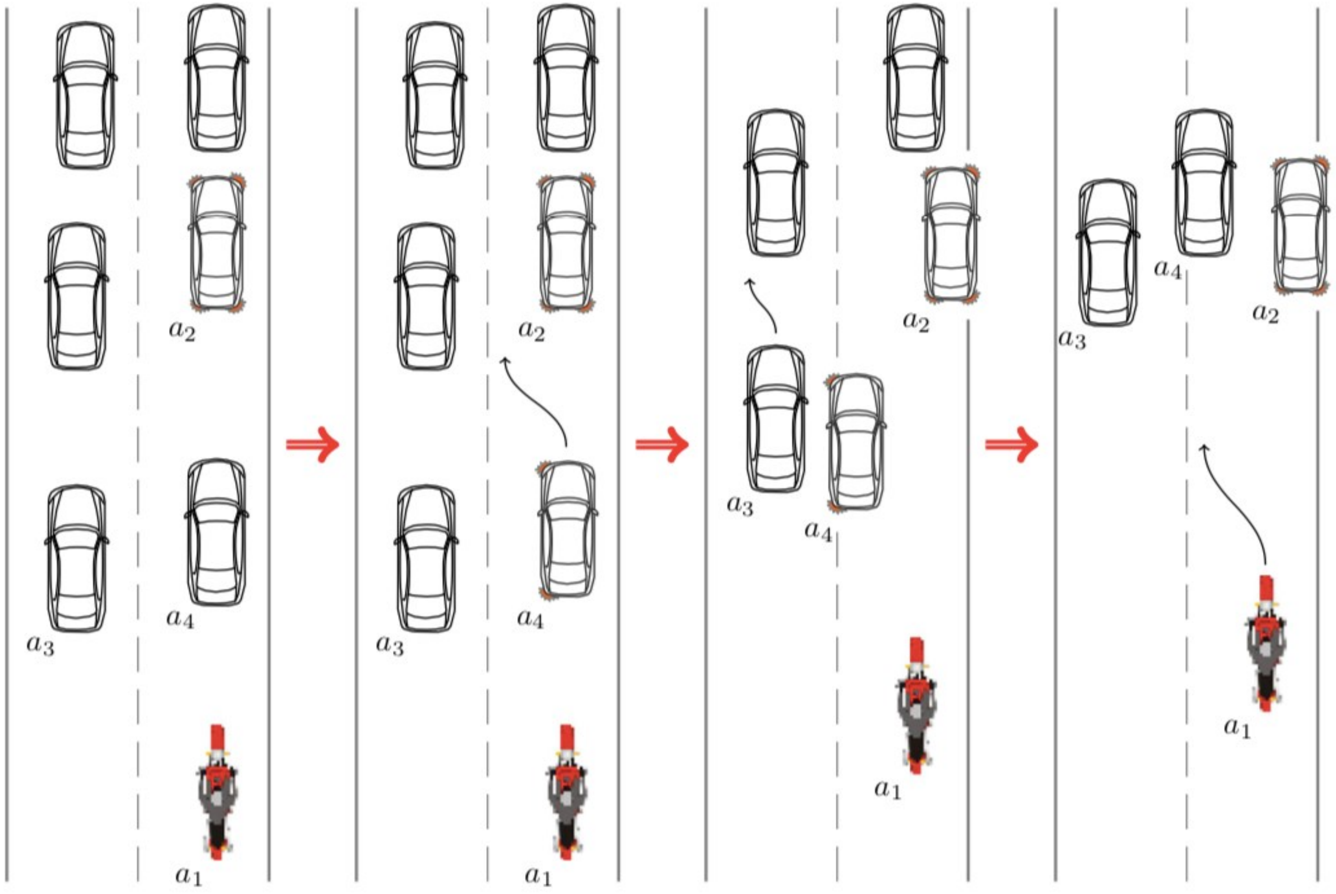


Fig 1: Non-normative behaviors in a situation representing a badly-parked vehicle

Virtual Lanes

- Bonte proposed a multi-agent solution for two-wheeled vehicles, with behaviors such as driving between cars.
- They are called “virtual” because they are not outlined on the road with markings.
- These lanes rely on free space between vehicles and the shoulder.

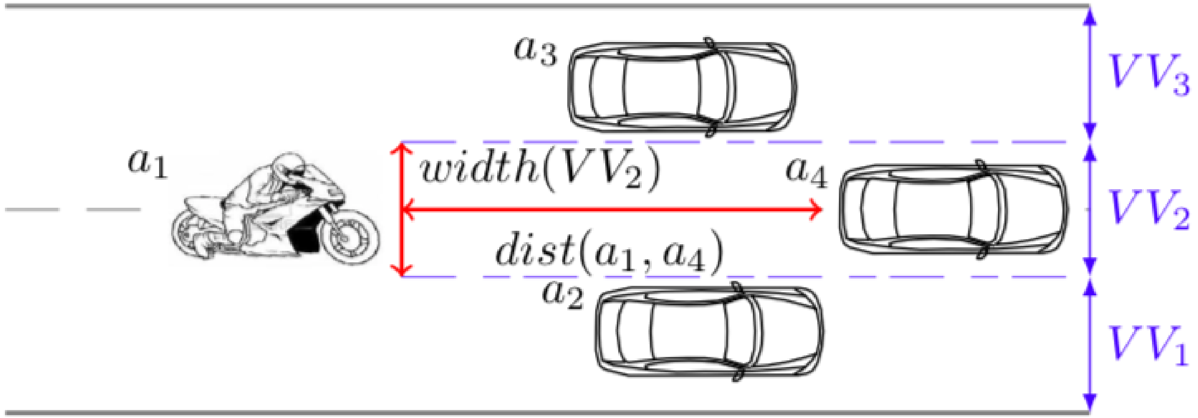


Fig 2: Description of virtual lanes

Definitions

- **Virtual Interval** (IV) is characterized by its width and is defined by the available space between the agent and an obstacle (*i.e.*, empty space in front of the vehicle)
- A **Virtual Lane** (VV) is one virtual interval or a subset of virtual intervals.
- Each virtual lane is referred to as VV_j characterized by a set of properties $P_j = \{p_{1j}, \ldots, p_{qj}\}$
- Properties can be broken down into three classes:
  - **Physical** $\left(width(VV_j), dist(VV_j)\right)$
  - **Flow-related** (traffic density (d), average vehicle speed (v_{avg}), std. dev of speed (σ)
  - **Wall effect** (speed (v_{wall}), stability (st_{wall}) and proximity ($prox_{wall}$) of surrounding environment)

Ego-centered Environmental Representation

- $A = \{a_1, a_2, \ldots, a_n\}$ is subset of all agents perceived by agent a_i.
- $Aff = \{VV_1, VV_2, \ldots, VV_l\}$ is set of affordances identified by agent a_i.
- $R = \{r_{a_i}(w_k) \;/ w_k \epsilon A \cup Aff\}$ is set of relations between a_i and a_k.
- Perception-Decision-Action (loop)

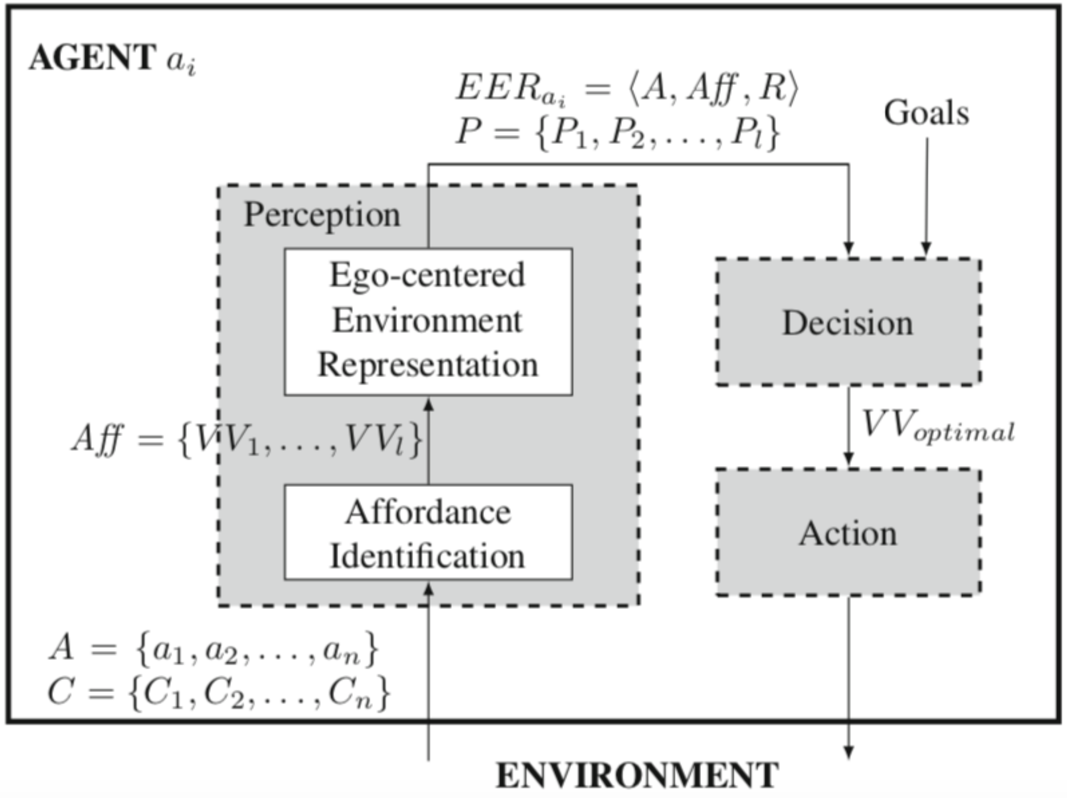


Fig 3: Agent a_i's architecture

Perception - Affordance Identification

- Agent browses environment starting with what is closest and moving further.
- In the context of our application, we assume there can be only five affordances.
  - Stay in own lane
  - Move left to adjacent lane
  - Move right to adjacent lane
  - Move left to reach a space to the left of adjacent lane
  - Move to right to reach a space to right of the adjacent lane

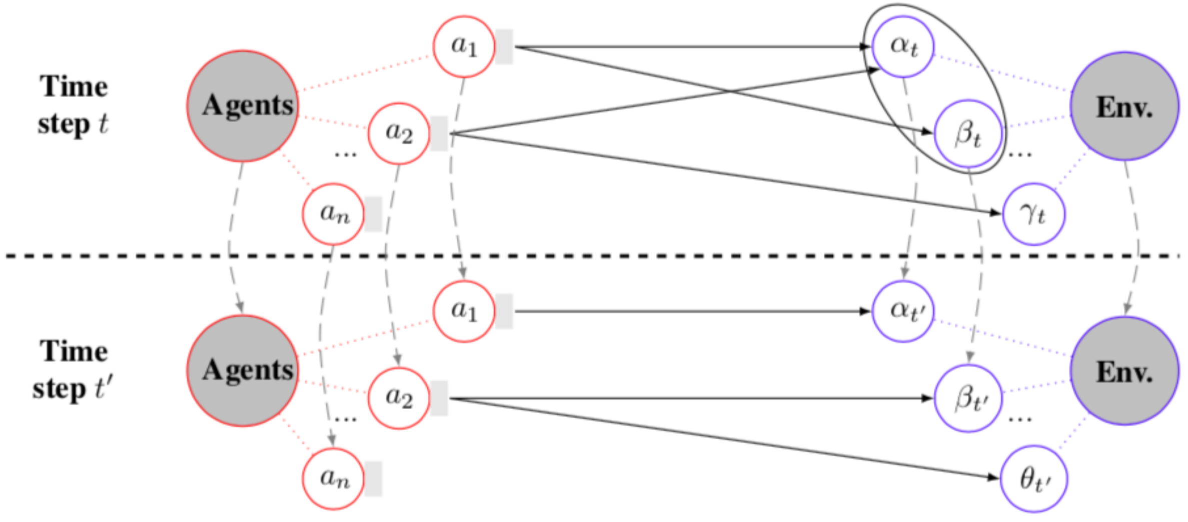


Fig 4: Agents – Environment interaction model

Perception – Identification Mechanisms

- If two intervals *X* and *Y* overlap, merge them.
- If interval *X* contains interval *Y* (*X* during *Y*), or *X* starts with *Y*, or X ends with *Y*, keep highest width in the interval set.
- Each agent has a choice: stay in current lane or change.
- Evaluation: compare the current speed of agent with estimated speed in the target lane.

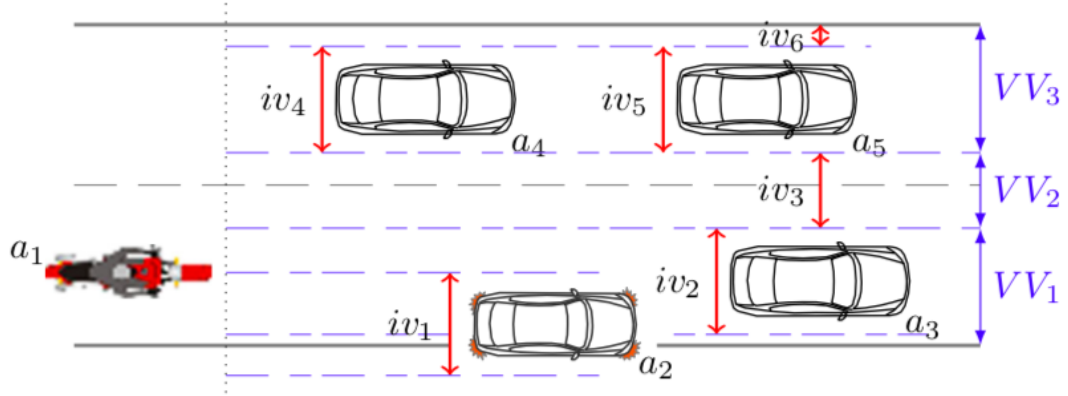
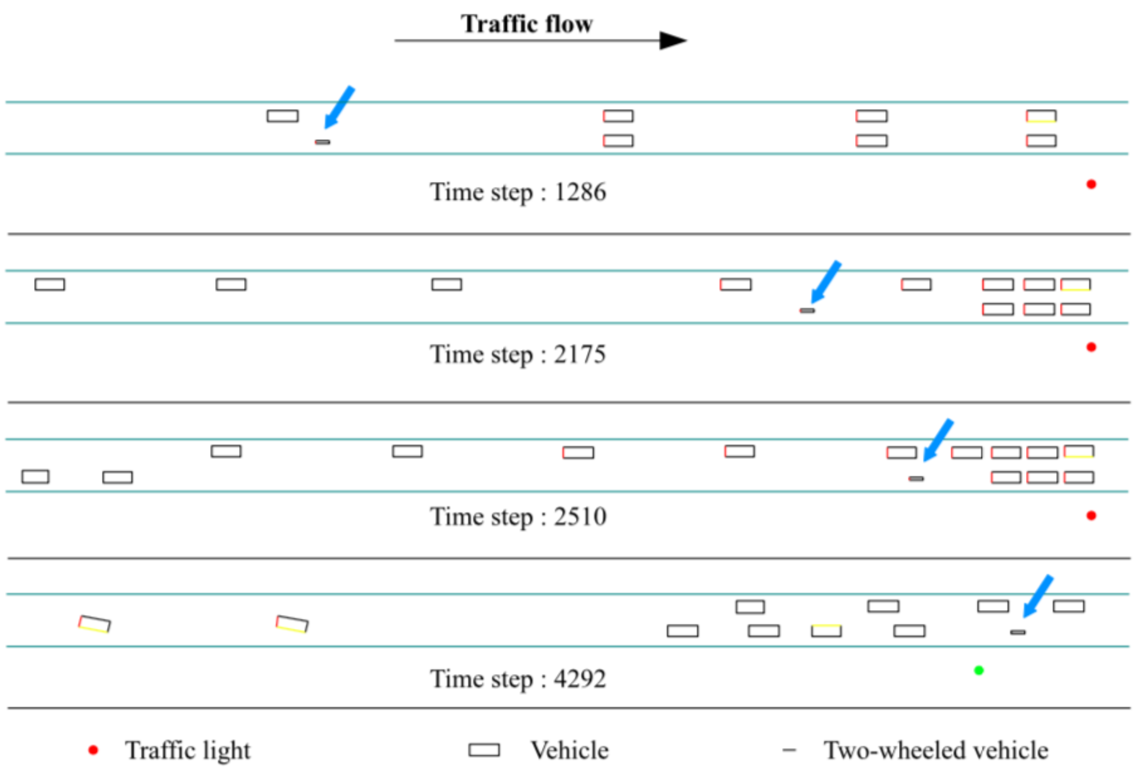


Fig 5: Detection of virtual lanes for a_1

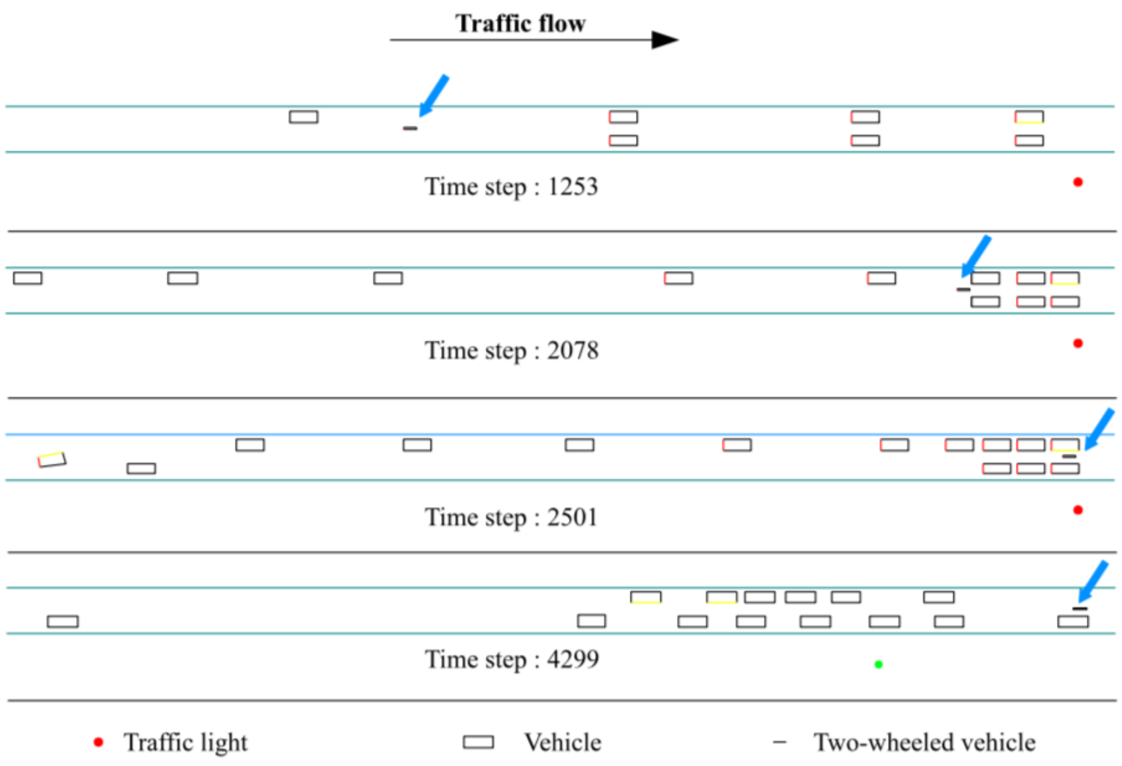
Decision and Action

- Agent is endowed with a decision-making mechanism to select an affordance to adopt from its affordance-based ego-centered environmental representation.
- It computes a fitness (score, interest value) for each affordance of Aff set
- $F(VV_j) = f(p_{1j}, \dots, p_{qj}, goals)$
- In our context, the goals correspond to objectives defined by the agent's itinerary
- $VV_{optimal} = argmax\ F(VV_j)$
- In our approach, the agent builds its contextual representation based on affordances and selects an optimal affordance.

Experiment 1: situation with a traffic light



(a) Reference model (without affordance-based model)



(b) with affordance-based model

Experiment 1: Cont'd (Evaluation)

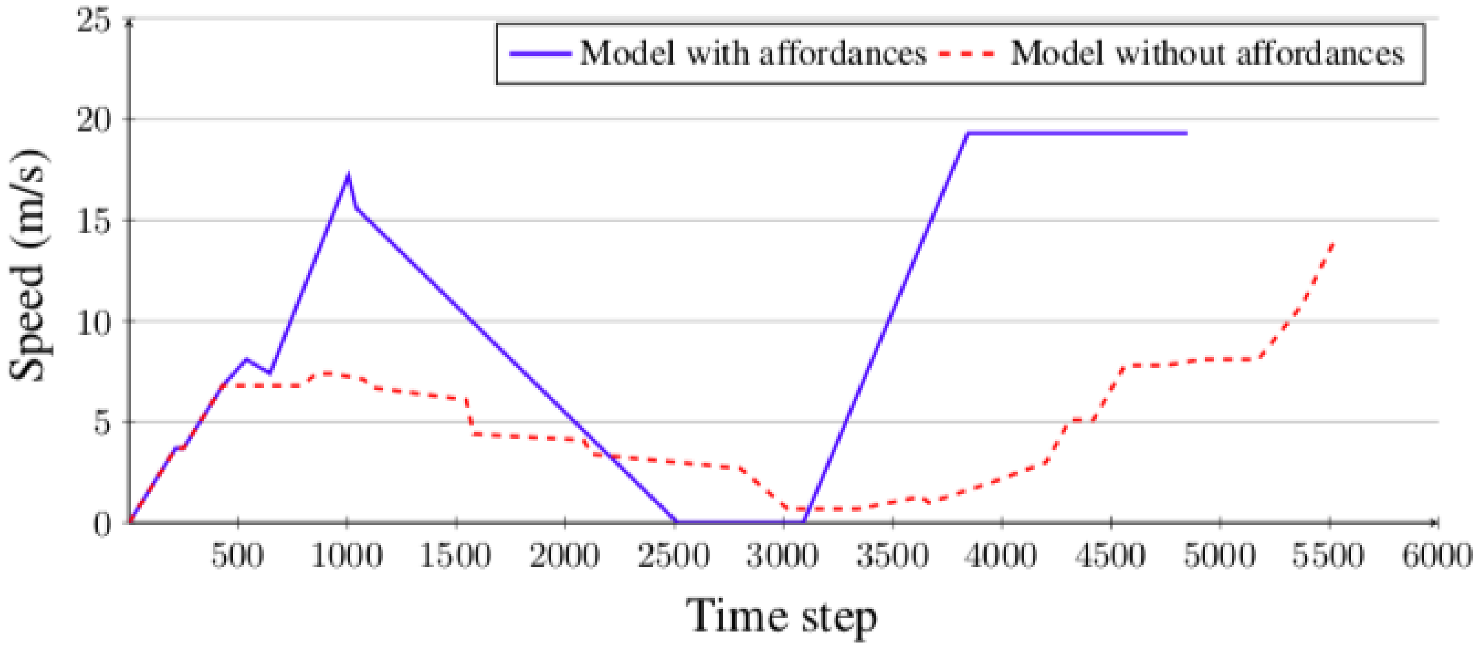


Fig 7: Speed of the two-wheeled vehicle with/without affordance-based model.

Experiment 1 - Cont’d - Analysis

- In scenario without affordance based model, the agent stays behind the different vehicles and stays in the same lane.
- It continues to move in its lane when the traffic light changes from red to green.
- In Affordance based model, the two-wheeled agent detects the potential emergence of a virtual lane (between the two rows of vehicles) afforded by the interaction of the other agents with the physical road structure.
- The speed variation is much lower for the model without affordances than for our model.
- The two-wheeled vehicle has already and stopped at traffic light in our model, while in the reference model, it continues to decelerate.

Experiment 2: situation with a traffic light

- We focused on the behavior of vehicle 0.
- Vehicles 1, 3 and 5 are going to turn right.
- Vehicles 2, 4 and 6 move and turn left.
- Vehicle 0 is blocked behind the row of vehicles turning right.

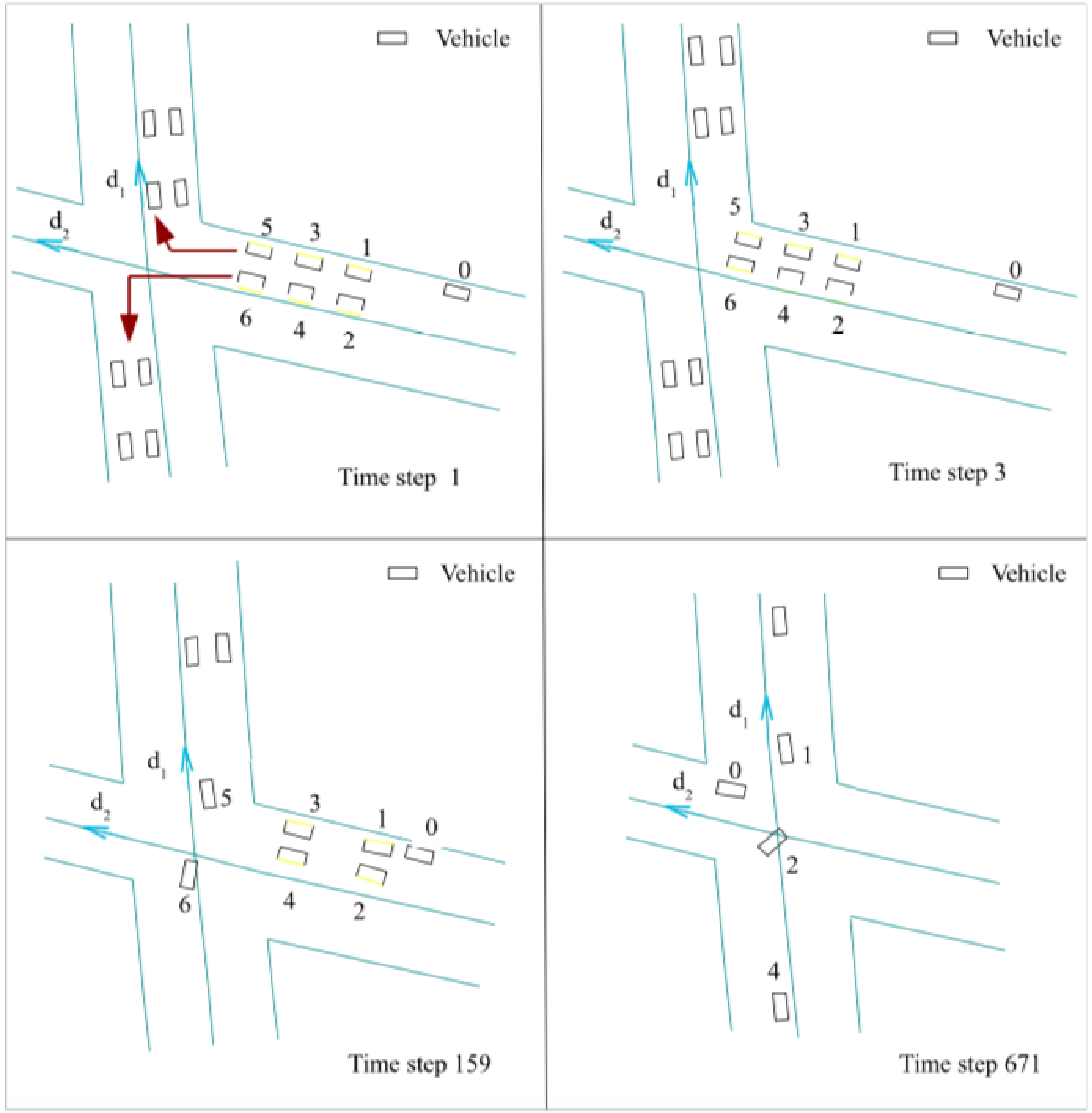


Fig 8 (a) intersection **without** affordance-based model

Experiment 2: situation with a traffic light (cont'd)

- Vehicle 0 creates a representation of the situation.
- Since vehicles 1, 3 and 5 turn right, they shift towards the right edge
- Vehicles 2, 4 and 6 follow the same behavior and turn left.
- 0 puts its turn signal on and starts moving in a virtual lane between the two rows of vehicles.

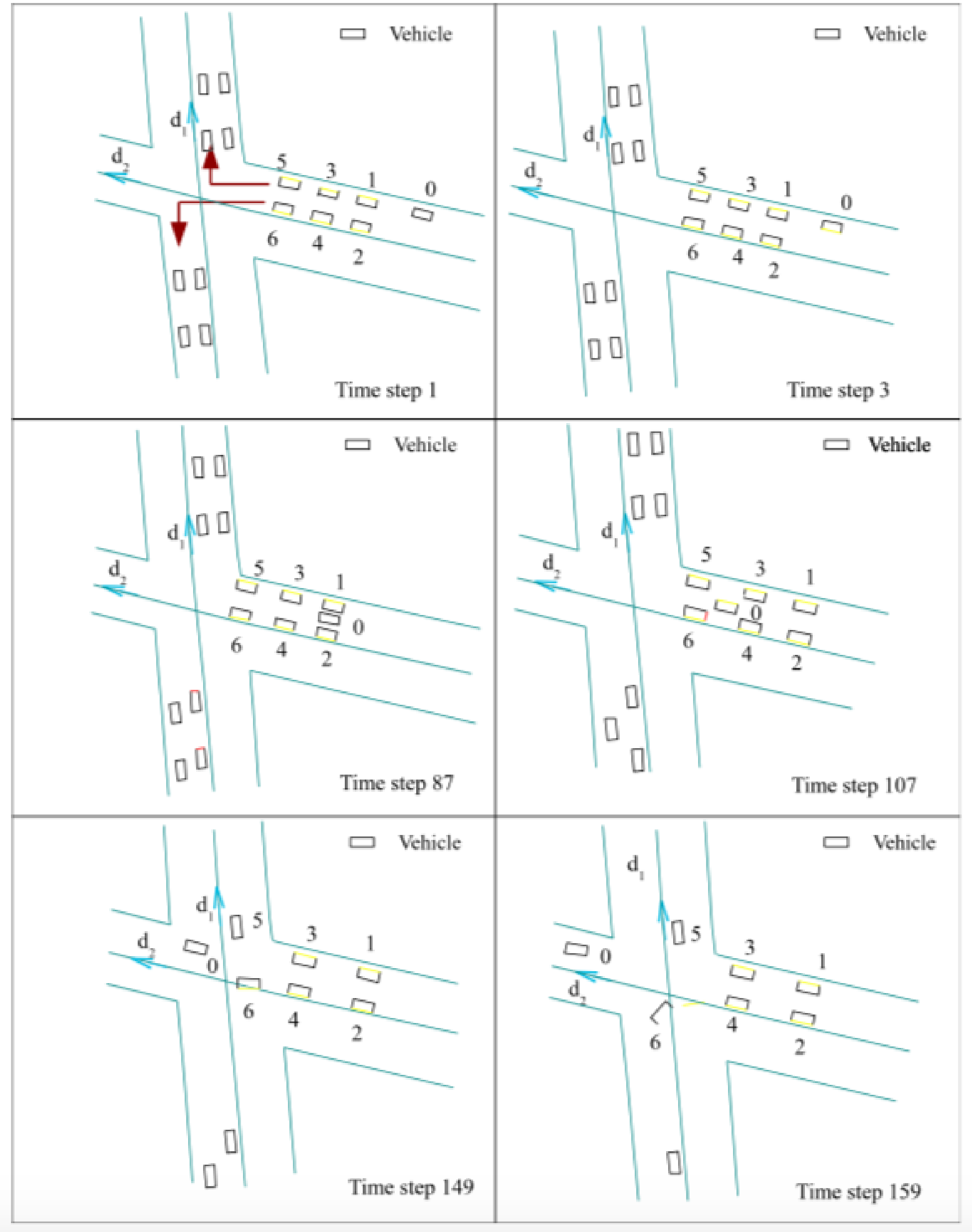


Fig 8 (b) intersection **with** affordance-based model

Experiment 3: real traffic simulation

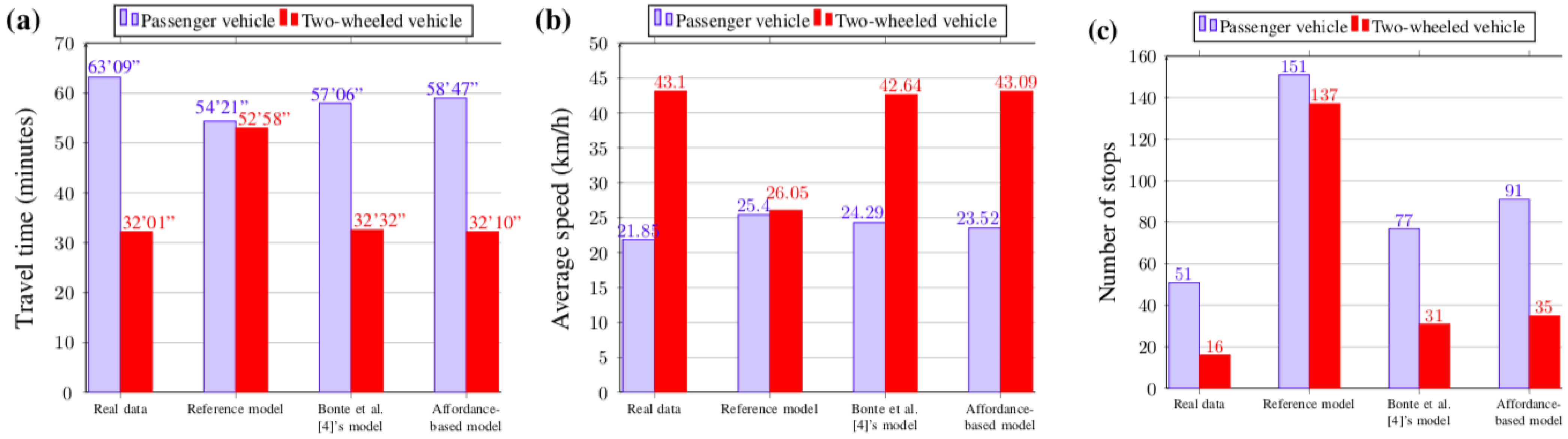


Fig 9: Comparison between Real and Experimental measurements on a route 23km long. (a)Travel Time, (b) Average Speed, (c)Number of Stops

Experiment 3 cont’d: Evaluation

- Affordance-based model considers that filtering is better tolerated in two-wheeled drivers than in car drivers.
- We observe that car drivers choose the virtual lane solution only if they engage in non-normative behavior (extreme cases).
- Choosing virtual lanes is not systematic; it depends on lane and vehicle characteristics (*e.g.*, size) and individual agent characteristics (distance to the norm).
- Proposed model is generic because it is not specific to one kind of driver.
- In the proposed affordance-based model, the affordance mechanism is the most costly process. So, the perception times of Fig. 12 are very acceptable
- However, our implementation of the affordance mechanism could be improved to reduce this cost.

Experiment 4: generalization regarding emergency vehicles (Not real data)

- The presence of an emergency vehicle (vehicle 1) leads other vehicles to shift to the right or the left, if possible.
- Scenario 1 : Assume that the emergency vehicle stops when the light changes red.
- Scenario 2 : Assume that the emergency vehicle goes through a red light.
- New spaces are produced when agents cooperate, and allow emergency vehicles to move faster, ensuring overall traffic fluidity.

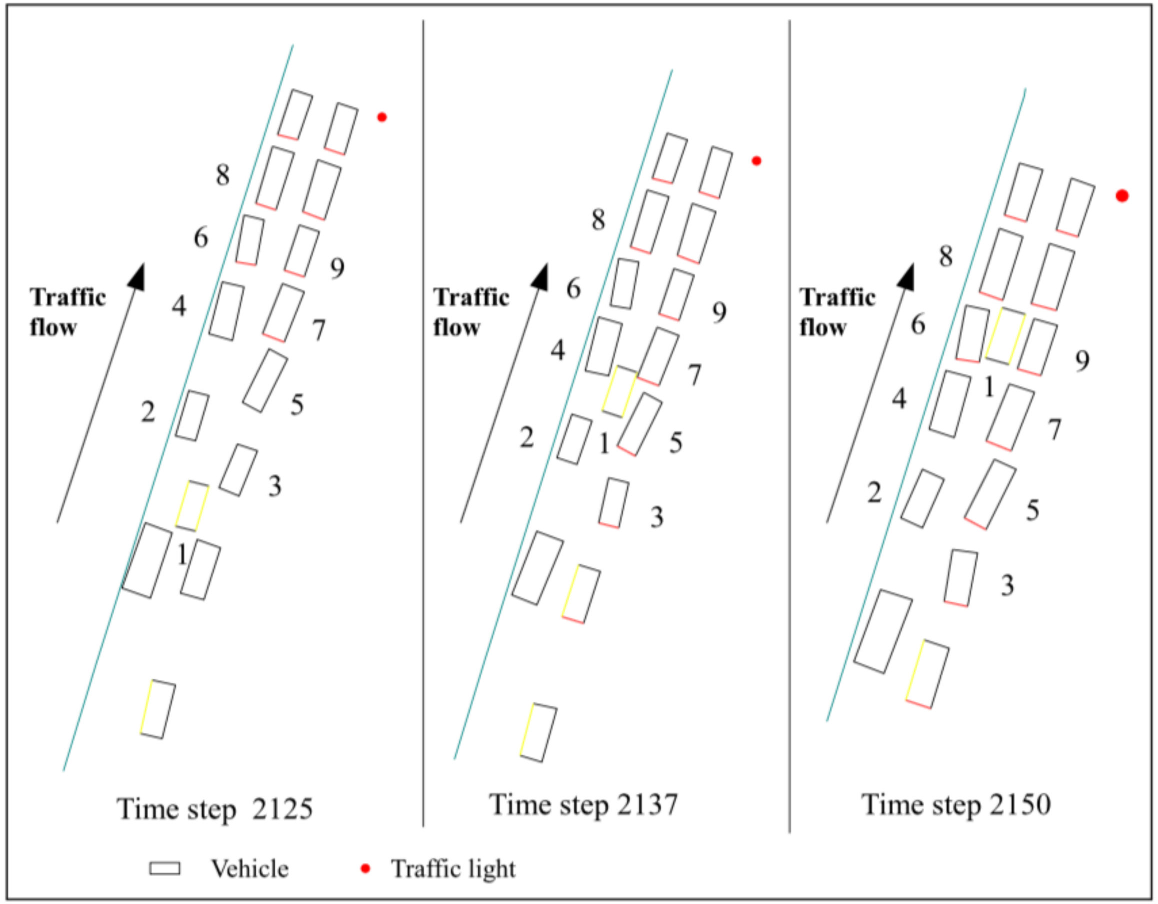


Fig 10: Appearance of an emergency vehicle in a traffic situation

Experiment 4 cont’d: Evaluation

- If Stops, emergency vehicle takes less time than a passenger vehicle but takes more time than a two-wheeled vehicle.
- If doesn’t stop, The emergency vehicle is faster than the others.
- Difference between two-wheeled and emergency vehicles is minimal in second scenario.
- Two-wheeled vehicle drivers can weave through road traffic whereas emergency vehicles cannot.

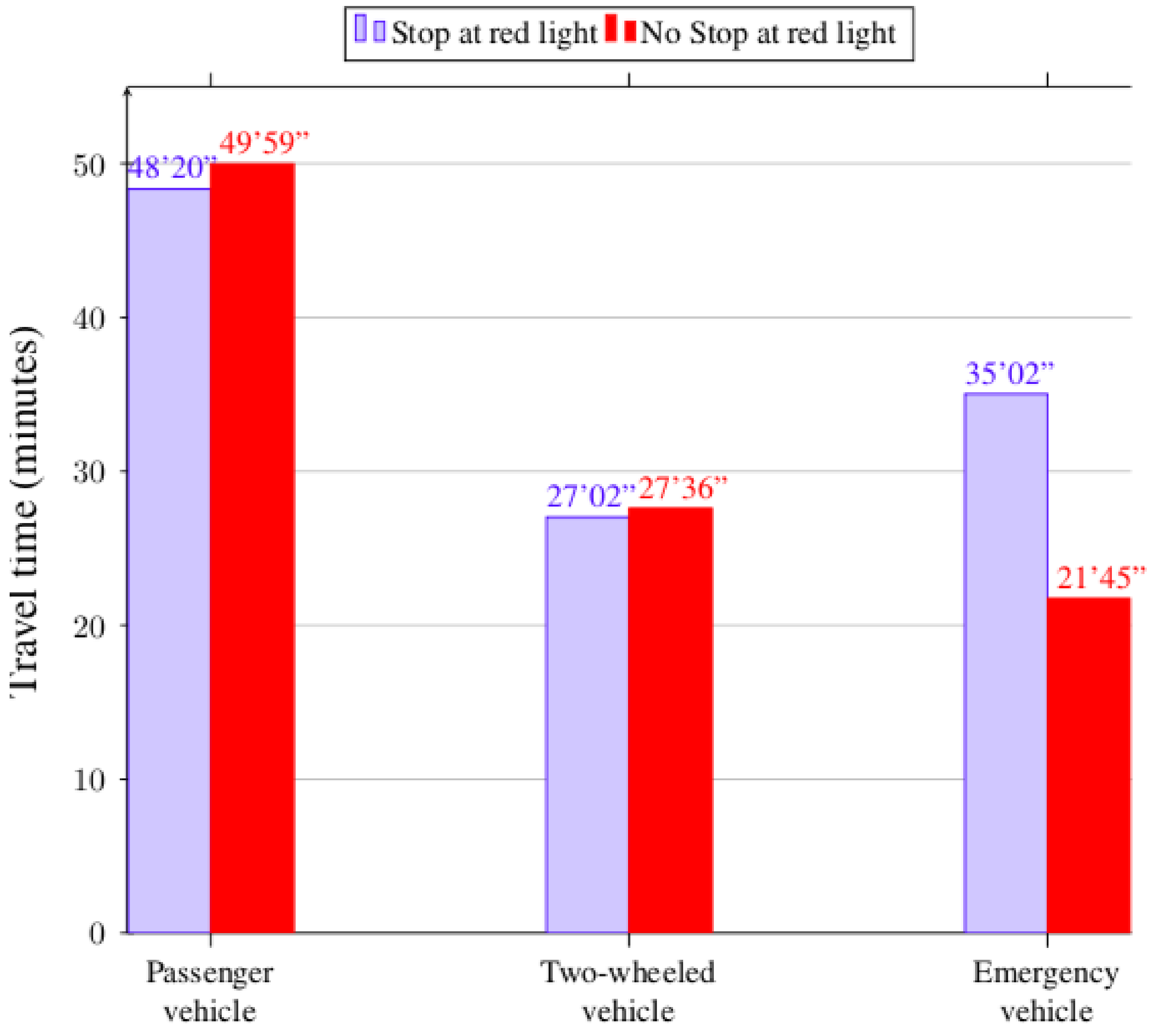


Fig 11: Travel time for different agent types based on emergency vehicle behavior

Conclusions

- Affordance based systems allow us to create an environment with varied perceptions of each agent.
- Although the work is specifically for traffic simulations, it could be applied in any context where an agent must continuously interact with the environment that is highly dynamic such as other path finding agents.
- Gives a model for storing relationships between agent and environment as virtual lanes or “possible path/action”
- Computationally expensive, especially in models with multiple agents.
- Additionally, if each agent is making their own virtual lanes and trying to move, it could in fact lead to further chaos.

Questions