Transport Efficiency of Mixed Traffic with E-bikes in Road Space Reallocation Scenarios

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1. Introduction
The e-bike use on public roads is increasing. Though categorized as bicycles in Japan, e-bikes have high average speed and quicker acceleration than conventional ones. The resulting impacts on transport efficiency and traffic risk require regulatory and design planning for their successful integration into the road space. Studies on e-bike mix traffic flow simulation\[1\] and road space reallocation have been conducted. However, there remain issues to address about road space reallocation corresponding to e-bike number.

The study aims to explore how to reallocate road space efficiently when considering different traffic density.

2. Methods
2.1 Agent settings
Traffic flow simulation is conducted using a multi-agent model. To simplify the flow, the model is temporal and spatial discrete, which means the coordination, time unit, and agents’ size and speed are integers. The time unit is tick, 1 tick = 1 sec. Agents are squares with size length 1. There are two kinds of agents: (1) Mobile agents, used to simulate vehicles. (2) Stationary agents, used to simulate different kinds of road, on which mobile agents move.

2.2 Forward movement
The Nagel-Schreckenberg (NaSch) traffic flow model is employed to determine the forward movement of mobile units. The movement for every unit in every tick can be divided into 4 steps.
1) Acceleration: 
\[v_{t+1} = \min(v_{t+1} + a, v_{\text{max}})\]
2) Deceleration: 
\[v_{t+1} = \min(v_{t+1}, d_t)\]
3) Randomization: 
\[v_{t+1} = \max(v_{t+1} - 1, 0)\]
4) Position update: 
\[x_{t+1} = x_t + v_{t+1}\]

where 
- \(v_t\) unit speed at time \(t\)
- \(v_{\text{max}}\) max speed this kind of unit can reach
- \(a\) randomized deceleration probability
- \(d_t\) distance to the previous unit at time \(t\)
- \(P_{\text{radm}}\) randomized deceleration probability
- \(x_t\) position of unit at time \(t\)

\[\min(x_1, x_2)\] the smallest among \(x_i\)
\[\max(x_1, x_2)\] the largest among \(x_i\)

2.3 Lane changing movement
Adding lane changing movement into the model, lane changing coefficient \(c_{m,t}\) (Eq.1) is promoted. A unit will choose the lane with maximal \(c_{m,t}\). If the unit change lane, its speed minuses 1. The settings of preference factors for different unit categories are set in Table 1.

\[c_{m,t} = d_{m,t} \ast f_{m,t}\] (1)

where
- \(c_{m,t}\) coefficient of lane changing to lane \(m\) at time \(t\)
- \(d_{m,t}\) distance to previous agent in lane \(m\) at time \(t\)
- \(f_{m,t}\) preference factor to change to lane \(m\) at time \(t\)

\[m = \begin{cases} 0 \text{ current lane} \\ 1 \text{ car lane side lane} \\ 2 \text{ sidewalk side lane} \end{cases}\]

2.4 Other settings
The input of the model includes vehicle amount, and lane permission. The length of the one-way road in model is 100m, thus the traffic density is amount/100m. Initially, mobile units are put randomly on lanes following the lane permission before moving tick by tick. Outputs in every tick are average speed of each kind of unit and the traffic volume, i.e. the number of vehicles passed through. Traffic volume of all kinds of units on road is the measure for traffic efficiency.

A course from randomized initial to 1200th ticks is one loop. Outputs from first 200 ticks are discarded and those from 201~1200th ticks are summed up. Average of the sums
from 50 loops is adopted as final results.

3. Results

To explore the efficiency-density relation of pedestrian traffic mixed or separated with bicycles, two kinds of road space reallocation are set: (1) 1m bike lane + 1m sidewalk; (2) 2m shared path for cycling. Pedestrian/bicycle ratio is constrained to 1:1, while the traffic density is variable. The result shows that in busy street with density of 34 * (pedestrians + bicycles)/100m, one shared path performs higher efficiency than separate ones. When bicycles changed to e-bikes, the threshold turns to 37, suggesting that separate path can help exhibiting e-bike speed advantage.

To investigate cyclist-car interfering, three road space scenarios are set (Figure 1). Car density is a constant of 5 vehicles/100m, and bicycle (or e-bike) density is variable. The result shows up to 7 bicycles or 8 e-bikes/100m, scenario (1)(2) have same efficiency but (2) uses space economically. Cyclist-car interference leads to inefficiency but when over 10 cyclists/100m, sharing 1m of car lane to cyclists can be a trade-off alternative to save place and improve efficiency.

To search efficient way to reallocate road space for bicycles and buses, three scenarios are set (Figure 2). Bus density is 1 vehicle/100m, having 5 riders. Result shows scenario (2) and (3) have the same efficiency, suggesting that when building a combination of bus lane and bike lane within 4m road width, there is no need to physically separate them. When bicycle density is higher than 16 vehicles/100m, sharing all bus space can be a more efficient alternative.

Reference

![Figure 1](Relation of e-bike density and traffic volume)

![Figure 2](Relation of e-bike density and passenger number)