Ride-hailing driver behavior in single-lane traffic

Olyn D. Desabelle,*[1] Damian N. Dailisan,[2] and May T. Lim[1]
[1] *National Institute of Physics, University of the Philippines Diliman, Philippines*
[2] *Analytics, Computing, and Complex Systems Laboratory, Asian Institute of Management, Philippines*
*Corresponding author: odesabelle@nip.upd.edu.ph

Abstract

We simulated Transportation Network Vehicles (TNVs) in single-lane vehicular traffic using the Nagel-Schreckenberg (NS) Model combined with a modified version of the Bus Route (BR) model. In our model: (1) Passengers spawn randomly; (2) TNVs slow down to pick up passengers; and (3) After dropping off passengers, TNVs either cruised or parked while waiting for a booking. At high vehicle densities ($\rho \geq 0.6$), parking-dominant systems produced higher throughput due to the decongestion brought by the reduced number of vehicles on the road. On the other hand, the interplay among passenger arrival rate, vehicle volume, and TNV count affected traffic flow and TNV trip counts.

Keywords: Transportation Network Vehicles, microscopic traffic simulations

1 Introduction

Transportation Network Companies (TNCs) such as Grab and Uber became popular in the Philippines in 2014, especially in Metro Manila. TNCs sought to provide a convenient mode of transportation through their smartphone app, and to provide an alternative source of income for private vehicle owners and drivers. TNCs also aimed to relieve traffic congestion, with the notion that less people will bring their private vehicles if they were given an option to conveniently book a TNC service [1, 2]. However, several reports have found that the emergence of the vehicles used by TNCs, also known as Transportation Network Vehicles (TNVs), either barely had any effect or worsened traffic congestion in different parts of the world [2–4]; thus it is important to see what factors involving traffic flow with TNVs may exacerbate the traffic problem. It is also vital to note that while TNV drivers receive financial subsidies, the majority of their earnings come from incentives they receive from trips they complete [5, 6]. As a result, TNV drivers adapt different strategies in order to maximize their profit. A specific aspect in the workflow of TNV drivers where they strategize is what they do after unloading their current passenger and while waiting to get a new booking. Some TNV drivers prefer to continue driving, also known as cruising, while some park in an establishment, usually where parking is free such as in gas stations or rest areas [5, 6]. This study aims to focus on how these TNV strategies, cruising and parking, affect traffic flow and TNV income. In order to do this, we simulated road traffic with the Nagel-Schreckenberg (NS) Model [7–9] and a modified version of the Bus Route (BR) Model [10].

2 Methodology

We refer to Fig. 1 for the simulation layout. We used a road $\mathcal{R}$ represented by a one-dimensional lattice of length $L = 500$. Each cell i (where $0 \leq i < L$) in the lattice had one of two states: (a) unoccupied

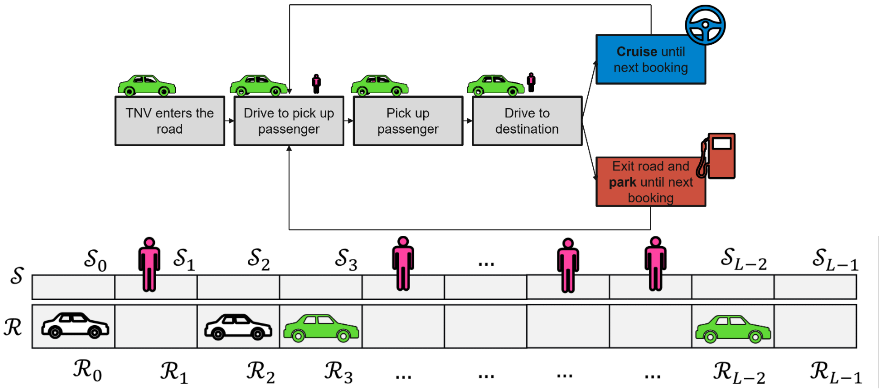

Figure 1: Diagram of the road system simulation and working behavior of emulated TNVs

or (b) occupied by only one vehicle. Assuming all vehicles on the road had the same bumper-to-bumper distance of 4 m, a lattice of 500 cells would suffice to model a straight city road that are approximately 2.5 km in length [11]. We initially distributed N vehicles randomly in the road lattice, given an initial vehicle density ρ where $\rho = N/L$. Among these vehicles, we assigned μ of them to be TNVs, given a TNV fraction f_{TNV} where $\mu = Nf_{\text{TNV}}$; we classified the remaining vehicles as non-TNVs. Each vehicle had its own position x_i^t for each timestep t, and after change in time Δt, it moved $\Delta x_i^{t+\Delta t}$ cells forward based on its current velocity v_i^t. Non-TNVs followed the NS Model in updating vehicle velocities and positions which incorporates acceleration, deceleration to avoid collisions, and stochastic slowdown behavior given a random slowdown probability p_{slow} [7–9]. Meanwhile, TNVs followed a modified version of the BR Model (mBR Model), which involves similar behaviors but includes slowing down to pick up or drop off passengers. We summarize vehicle movement in Eq. 1:

$$\begin{aligned}\Delta x_i^{t+\Delta t} &= \max(0,\ \min(v_{\max}\Delta t,\ g_i^t,\ (v_i^t+1)\Delta t) - \xi_i^t(p_{\text{slow}})\ ) \quad \text{[Non-TNV]}\\ \Delta x_i^{t+\Delta t} &= \max(0,\ \min(v_{\max}\Delta t,\ g_i^t,\ (v_i^t+1)\Delta t,\ \epsilon_i^t) - \xi_i^t(p_{\text{slow}})\ ) \quad \text{[TNV]}\end{aligned} \tag{1}$$

In Eq. 1, g_i^t refers to the gap between a vehicle and the vehicle in front of it. The quantity $\xi_i^t(p_{\text{slow}})$ denotes the random slowdown behavior of all vehicles, where $\xi_i^t(p_{\text{slow}}) = 1$ cell with slowdown probability p_{slow}, else $\xi_i^t(p_{\text{slow}}) = 0$. TNV movement has a unique slowdown factor $\epsilon_i^t\Delta t$ in anticipation of passenger pick-up or drop-off: $\epsilon_i^t\Delta t = h_i^t$ if passenger headway $h_i^t \geq (v_i^t - 2)\Delta t$, else $\epsilon_i^t = 0$ [7, 9, 11]. We also imposed a speed limit $v_{\max}$ such that $0 \leq v_i^t \leq v_{\max}$. We took cue from previous works that use $v_{\max} = 5$ cells per timestep, $\Delta t = 1$, and slowdown probability $p_{\text{slow}} = 0.2$ for runtime efficiency without compromising the representation of real traffic [7, 9, 11]. Correlating the common 60 km per hour speed limit in city roads, each simulation timestep represented approximately 1.65 s in real time [11]. Each vehicle updated its position in parallel after each timestep, following periodic boundary conditions, for a total of $T = 4000$ timesteps. Passengers simultaneously arrived at the sidewalk lattice $\mathcal{S}$ beside the road lattice $\mathcal{R}$ at a rate α.

In our mBR Model, TNVs followed the work cycle in Fig. 1, involving slowing down to load a passenger, driving to their destination, slowing down to unload, and waiting for their next trip. Contrary to the BR Model [10, 11], we set the maximum TNV passenger capacity to 1 to ensure their work cycle. For simplicity, we also set the drop-off points of TNV passengers at an arbitrary distance $+L/2$ from their pick-up point. After unloading their passenger, TNVs cruised if they were in cruising-dominant (CD) systems; TNVs in parking-dominant (PD) systems parked instead (Fig. 1). When TNVs cruise, they continued driving after unloading a passenger. When TNVs parked, they were removed from the system for at least an arbitrary waiting time $\tau = 2$ timesteps after they completed their trip as if they instantly moved to an off-road parking lot. Afterwards, they returned to their previous position should it be unoccupied, else they were forced to wait.

We used the throughput q as a measure for traffic flow. For the simulation with discrete timesteps we measured it as the time-averaged sum of all vehicle velocities v_i over the total number of road cells L [11]. On the other hand, we obtained the average number of completed trips per TNV ($\text{trips}_{\text{ave}}$) as a measure of average TNV income. We summarize these recorded quantities in Eq.2a and Eq. 2b.

$$q = \frac{1}{T}\sum_{t=0}^{T}\frac{\sum_{i=0}^{N} v_i^t}{L} \tag{2a}$$

$$\text{trips}_{\text{ave}} = \sum_{t=0}^{T}\frac{\sum_{j=0}^{\mu}\text{trips}_j}{\mu} \tag{2b}$$

3 Results and discussions

The system with no TNVs ($f_{\text{TNV}} = 0$) produced a throughput curve (q curve) exhibiting a reverse lambda structure with a peak throughput at its critical density $\rho_c = 0.167$ (Fig. 2). This agrees with the theoretical pattern of purely NS models that peak at $\rho_c = 1/(v_{\max}+1)$ [7, 9]. Changes in q curves took place in $f_{\text{TNV}} \neq 0$ systems due to the unique movement of TNVs. Low passenger arrival rate systems with $\alpha = 10^{-3}$ retained the reverse lambda pattern, but achieved much lower throughput at densities of $\rho \leq 0.3$. Since there were very few passengers to make trips, the slowing down of the few TNVs (looking to load or unload passengers) was still slightly overwhelmed by the NS-like flow of the

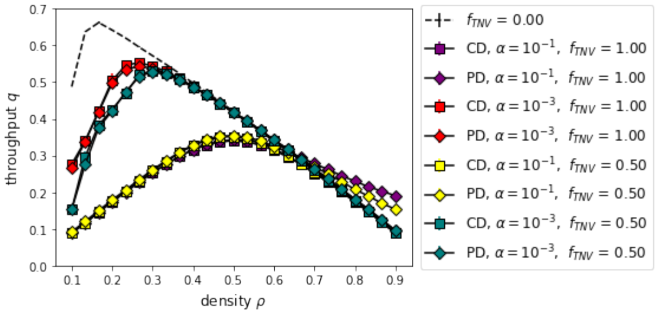

Figure 2: Fundamental diagram of the road systems

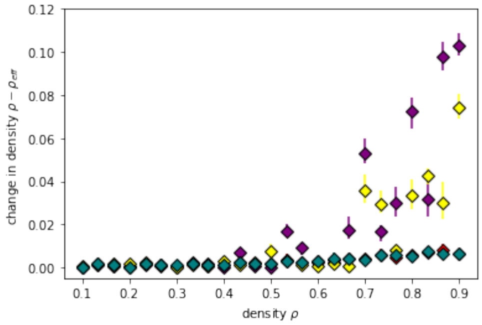

Figure 3: Change in density $\rho - \rho_{\text{eff}}$ vs. initial density ρ of PD systems

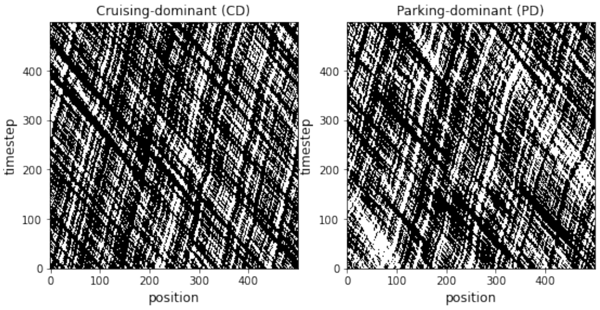

Figure 4: Spatio-temporal diagrams of CD (left) and PD (right) systems at $\rho = 0.8$, $\alpha = 10^{-1}$

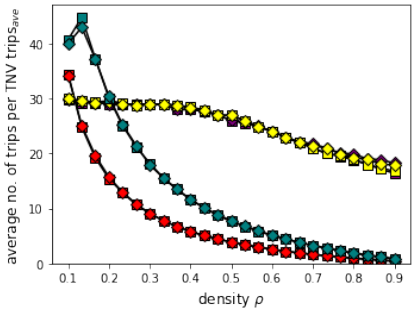

Figure 5: Average TNV trips vs. initial density ρ

many other vehicles: the non-TNVs and the TNVs without passengers to pick up or drop off. This was also shown by the subtle differences among systems with same $\alpha = 10^{-3}$ but different TNV fractions $f_{\text{TNV}} = 0.5$ or $f_{\text{TNV}} = 1.0$ where we observed higher throughput with higher f_{TNV}. The $\alpha = 10^{-3}$ systems obtained their peak throughputs at slightly higher densities around $0.25 \leq \rho \leq 0.3$, after which their q curve mimicked that for the $f_{\text{TNV}} = 0$ system. In this high density regime, the effects of the NS and mBR Models were identical due to congestion. High passenger arrival rate systems with $\alpha = 10^{-1}$ exhibited parabolic q curves instead, with peak throughputs attained at higher densities near $\rho = 0.5$. The increased arrival rate of passengers in these systems resulted in the shift from a NS-dominated system to an mBR-dominated system, since the high demand for TNVs triggered their occasional stopping behavior involved in loading and unloading passengers. Systems with similar α and f_{TNV} but different dominant strategy still produced similar q curves in the lower to middle density regions. It is notable that whichever strategy TNVs opted to use, the mere introduction of TNVs drastically slowed down traffic, especially in higher α where TNVs much more frequently stopped for passengers, lowering throughput q to at least half compared to the no-TNV system (see Fig. 2).

In the high density region of $\alpha = 10^{-1}$ systems, CD setups produced q curves similar to that of the no-TNV system; on the other hand, PD setups achieved slightly higher throughputs. We recall that for PD systems, the TNVs momentarily left the road to park. This was to emulate off-road parking, not to be confused with curbside parking [12]. As TNVs exited the system, the initial road density ρ reduced to a new effective road density ρ_{eff} where $\rho_{\text{eff}} < \rho$. This ρ_{eff} barely changed for the low $\alpha = 10^{-3}$ due to the few trips that TNVs made with the few passengers; but the high $\alpha = 10^{-1}$ systems with higher TNV fraction f_{TNV} and initial road density ρ exhibited larger changes in density (Fig. 3). We illustrated this decongestion in the spatio-temporal (ST) diagrams of systems with the same initial road density $\rho = 0.8$ and passenger arrival rate $\alpha = 10^{-1}$ but different strategies (Fig. 4). Each row of the ST diagrams denoted the road lattice for each timestep where dark cells represented vehicles. Fewer dark spots occupied the ST diagram of the PD system, depicting fewer vehicles on the road. At lower densities, parking and cruising strategies provided similar outcomes; the only factors that affected traffic flow were passenger arrival rate α and TNV fraction f_{TNV}, which roughly correspond to demand and supply of TNV services. The strategies also did not produce distinct changes in average TNV trips. Instead, this quantity was more governed by road conditions. The effect of f_{TNV} was indistinguishable in high $\alpha = 10^{-1}$ setups, as there was too much demand for TNVs (Fig. 5). Instead, they were more affected by the sheer volume of vehicles on the road which slowed down traffic and trip completion, as exhibited by the slow and nearly monotonically decreasing relationship between trips$_{\text{ave}}$ and ρ. For lower $\alpha = 10^{-3}$, higher f_{TNV} was detrimental to TNV trips. The effect of road density was also notably different; low ρ, low α setups completed more trips than the low ρ, high α ones. However, higher ρ drastically decreased trip counts for low α systems. The complicated relationship between trip count and the road conditions came with the total TNV count μ being dependent on vehicle density ρ and TNV fraction f_{TNV} (recall $\mu = Nf_{\text{TNV}} = \rho L f_{\text{TNV}}$). Increasing ρ entailed more vehicles on the road, while increasing f_{TNV} brought more frequently stopping vehicles – both effects slowed down traffic flow and hindered TNVs from completing their current trips. However, more TNVs also allowed for more trips to be completed. A deciding factor on whether which effect would have much more influence on trip count was the passenger arrival rate α, as it dictated whether TNVs had to stop more often to pick up or drop off passengers; otherwise they would have behaved like non-TNVs. Given the simple approach to TNV driving behavior modeling, we expect that in multi-lane systems, lane-changing mechanics will play a significant role in the relationship among these conditions. Improving the model in other ways such as by generating non-static trip distances and giving TNVs the option to reject rides could also show more interactions with system conditions as well as better emulate real-life scenarios.

4 Conclusions

We observed no changes between cruising or parking strategies on average trips per TNV and on traffic flow for the lower density regions. Road conditions such as vehicle volume, passenger arrival rate, and TNV count affected the traffic flow and average TNV trips more for these systems. In highly vehicle-dense roads, TNVs parking while waiting for their next trip resulted in less congested traffic flow. This supports the tendency of more experienced TNV drivers to park in their downtime rather than cruise coming from real accounts [5, 6]. Parking not only reduces the fuel expenses of TNVs but also eases traffic flow especially at high density settings such as rush hour. It may be worth looking into reducing the likelihood of TNVs to cruise such as imposing a more efficient parking space planning [12] or providing parking availability data in TNC apps [5, 6]. Coupled with increasing TNV driver subsidies or wages, reducing the demand for TNVs overall by improving public transportation would be a more ideal solution, as exemplified by the negative effect of TNV presence on traffic flow [4, 6, 13].

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