DEVELOPMENT OF A SIMULATION SYSTEM FOR JEEPNEY STOP VICINITY LOCATED IN FRONT OF A SHOPPING CENTER

Hilario Sean PALMIANO
Graduate Student (Doctoral Program)
Interdisciplinary Graduate School of Science
and Engineering
Tokyo Institute of Technology
Midorigaoka Bldg. 5, 2-12-1, Ookayama,
Meguro-ku, Tokyo, 152-8552, JAPAN
Fax: +81-3-5734-3578
Email: sean@plan.cv.titech.ac.jp

Abstract: Most person trips in Metro Manila use public transit vehicles (PUV). People tend to gather at transit stops, and as a result PUVs also gather and dwell on the road. This behavior causes obstruction to traffic flow. It becomes even more important to evaluate this obstructing effect at areas near traffic generators or large-scale developments (e.g. shopping centers). This study aims to develop a simulation tool for evaluating the influence of PUVs on traffic in the vicinity of jeepney stops. The developed system is capable of simulating the distinctive traffic phenomena observed at transit stops in Metro Manila. The task includes: 1) modeling non-observance of lane behavior, and 2) modeling the dynamic interaction between the PUV and passengers waiting at curbside at the jeepney stop.

Key Words: traffic micro-simulation, transit stops, jitney, impact analysis

1. INTRODUCTION

1.1 Background

Public transport share of total person trips in Metro Manila is 70% in 1996 (MMUTIS, 1998). Among the largely road-based public utility vehicles (PUVs), the paratransit mode called jeepney[1] is most popular, servicing nearly 40% of total person trips. The rest of transit trips are divided among buses (15%), tricycles, and the FX[2]. The remaining 2% is shared by LRT and heavy rail, which ply along very limited number of corridors in the metropolis. Majority

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[1] The jeepney "is a Philippine jitney bus converted from a jeep" (Merriam-Webster dictionary online, http://www.m-w.com).

[2] The FX is an air-conditioned 10-seater PUV recently gaining popularity.

of the PUVs are low capacity vehicles (18 to 22 passengers for jeepney). Because of the combination of high demand and low PUV capacity, these vehicles operate at high volume and very high frequency, which makes the service quite convenient on one hand. However, at transit stops where people tend to gather, jeepneys and other PUVs would also tend to accumulate and dwell on the road resulting in some obstruction to traffic.

Transit stops[3] in Metro Manila are quite different from conventional bus stops found in developed countries. Firstly, although location of transit stops may be fixed or designated, it is common to observe random stop locations induced by passenger demand. Secondly, there is no fixed number of berths in jeepney stops. The number of stopped PUVs on queue is determined by passenger demand and available road space. So it is common to see long queues on the curbside lane at busy transit stops, and even double queues. (This is probably the reason why it is more appropriate to refer to stops as "loading and unloading areas", as locally called). Furthermore, most transit stops are without turnouts so PUVs dwell on the carriageway. Finally, jeepney service is not scheduled but operate with high frequency.

The abovementioned aspects, combined with the naturally aggressive behavior of drivers observed in Metro Manila, (to be discussed in more detail in Section 3) can cause network delays and decrease in link capacity. There are many efforts being done to relieve the metropolis of congestion. Objectively investigating the problem at transit stops in Metro Manila can help implement appropriate policies. Unfortunately there is still inadequate study on this area.

Recently, there has been effort in drafting the Philippine guideline for conducting traffic impact analysis (TIA) for site developments. TIA is a special study that seeks to evaluate the impact of trips generated by significantly sized developments on the surrounding traffic, so that proper measures can be advocated to mitigate the negative impact (ITE, 1991). Many examples adopted come from developed countries where site impacts are mostly attributed to site-generated private vehicles. Understandably, the analytical procedures are also focused on impact of private vehicle trips. Public transport use is popular in Metro Manila, so it is quite logical that site development trip generation would have high transit modal share. Taking the shopping center as an example of significantly sized development, Palmiano (2000) shows that about 80% of patrons use public transport and the result is very high frequency on-street stoppages at transit stops servicing the shopping center. Large-scale developments mean very high passenger demand, and transit stops located in front of shopping centers can cause bottlenecks. TIA for Philippines must give appropriate focus on impacts of transit trips and consider the effect of transit behavior at stops on traffic. But to accomplish this, first there is a need to develop the necessary analytical tool for studying traffic flow and related behaviors in the vicinity of jeepney stops.

1.2 Objective of this study

The purpose of this research is to develop a new traffic simulation system that reproduces traffic conditions in the vicinity of jeepney stops. The system will allow objective analysis of the effects on traffic flow due to the interrelated behaviors observed at the jeepney stop.

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[3] 'Jeepney stops' and 'transit stops' are used interchangeably in this paper. In Metro Manila, although there are cases of exclusive stops for particular modes, in general, a transit stop can be used by any mode -- more commonly by the jeepney.

2. NECESSITY OF DEVELOPING A NEW TRAFFIC SIMULATION SYSTEM

To date, there are numerous traffic micro-simulators already developed, commercial or otherwise. The subject of simulation of many of these is to reproduce the traffic conditions observed in developed countries. There are also simulation models designed specifically for TIA or used to conduct TIA. However, none can reproduce the specific traffic phenomena observed at jeepney stops in Metro Manila with reasonable realism and detail. Users of commercial simulators are often forced to find creative ways to "artificially" effect a desired traffic behavior by trying various configurations and making use of available model features.

Regidor & Sigua (1995) presents the first effort in simulating the jeepney stop environment for the purpose of formulating effective stop location policies. The paper gives detailed description of the jeepney stop environment and recognizes the interaction between passengers and jeepneys. The simulated one-lane link is divided into discrete cells and vehicles are released stochastically but travels with constant speed. The program applies stochastic model of passenger arrivals at various locations to simulate designated or random stop location. Understandably, the model is constrained by simplifying assumptions such as one-lane road, only 2 types of vehicles (jeepney and others), and constant speed for all vehicles. Perhaps the constant speed assumption introduces significant limitation, considering that many traffic micro-simulators employ car-following algorithms that allow more realistic variation of speeds.

There is a need to develop a new traffic simulation system that will reproduce the distinct traffic phenomenon in Metro Manila transit stops, which can be used as a quantitative tool in analyzing traffic effects.

3. OBSERVED TRAFFIC PHENOMENON IN THE VICINITY OF JEEPNEY STOPS

In this section the condition and characteristics of road traffic near jeepney stops are discussed. Observations are based on related studies and from video footages of Metro Manila road traffic.

3.1 General conditions of through traffic

Non-observance of road lanes

Video footage of road traffic near jeepney stops show that traffic seems to be in disarray because a significant number of vehicles do not travel neatly and centered along nominally set lanes. One observable traffic characteristic of road traffic in Metro Manila is that vehicles have the propensity not to observe traveling along normal carriageway lanes (Picture 1). As a simple investigation, video footage of a 4-lane road section near a jeepney stop was viewed and the frequency of vehicles not observing normal lanes (vehicles that touch the lane markings, thus not centered within lanes) was counted. Vehicles performing a normal lane change (from one lane to another lane such that it is centered on a lane before and after the maneuver) were excluded from this count. Table 1 shows the count in detail. The average 5-minute frequency of non-observance of lanes recorded is 14.3% with a maximum of 22% within the period of observation.

Table 1. Survey result: frequency of lane non-observance

Time (h)	Total Traffic Volume	Number of Vehicles Crossing lane marks	%
1240-1245	141	31	22.0
1245-1250	147	18	12.2
1250-1255	159	13	8.2
1255-1300	136	21	15.4
1300-1305	146	22	15.1
1305-1310	118	17	14.4
1310-1315	119	15	12.6
TOTAL	966	137	14.3

There are also instances, especially at high traffic volumes, when vehicle traffic on a nominal 2-lane carriageway spontaneously "adjusts and squeezes" until traffic runs with 3 lanes. Also, it is observed that when a four lane undivided urban road, which normally runs with 2 lanes of traffic in opposite directions, have unequal directional distribution, traffic would spontaneously adjust and run with 3 lanes on the direction with heavier volume and a lane on the other. Since road capacity is conventionally related to the number of lanes, there may be reason to say that in Manila, where there is propensity for non-observance of lanes, road capacity may instead be closer determined using total road width rather than number of lanes.

Picture 1. Propensity for non-observance of lanes; traffic along EDSA

Aggressive lateral movements

In Metro Manila, drivers are generally known to be aggressive. This is observed to be even more conspicuous near jeepney stops where there is more tendency for both transit vehicles and other vehicles to perform aggressive lateral movements (lane changing and swerving). This behavior results in frequent unavoidable braking and affects lane utilization (Regidor *et al.*, 1999). Thus, it can be said that such phenomenon results in traffic delays and even reduction in road capacity.

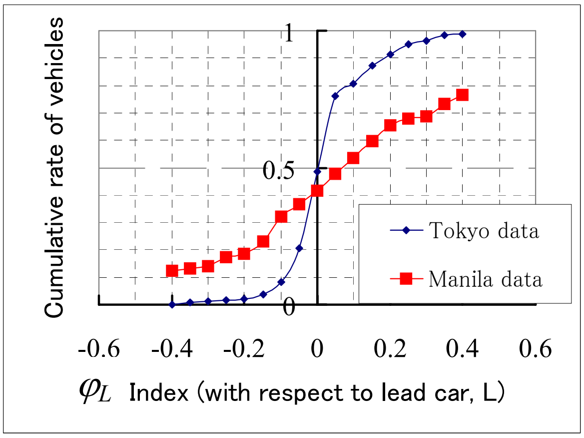
Nakamura *et al.* (1992) used an index that helps describe aggressiveness related to lane changing. The index, φ, is the rate of change of distance headway, between a subject vehicle performing the lane change (S), and either the lead vehicle in the target lane (L), or the rear vehicle in the target lane (R). The expression is shown as Equation. 1. A negative value of φ indicates aggressive or risky lane changing behavior, i.e., more negative means more aggressive.

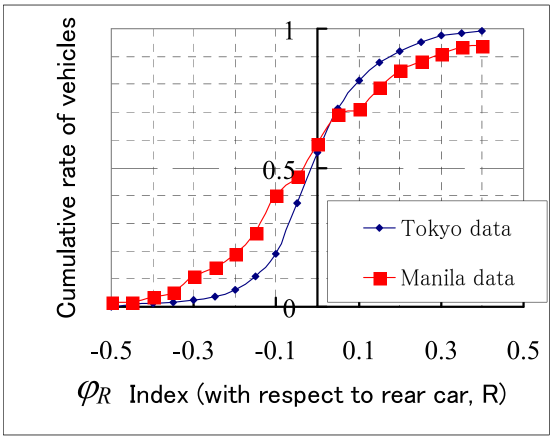
$$\varphi_L(t) = \frac{V_L(t) - V_S(t)}{y_L(t) - y_S(t)} = \frac{1}{S_L} \cdot \frac{dS_L(t)}{dt} \tag{1}$$

$$\varphi_R(t) = \frac{V_S(t) - V_R(t)}{y_S(t) - y_R(t)} = \frac{1}{S_R} \cdot \frac{dS_R(t)}{dt}$$

Where:
S, L, R : subscripts for subject lane changing vehicle, lead vehicle, and rear vehicle, resp.
$\varphi_L(t)$, $\varphi_R(t)$: rate of change of distance headway for L and R, resp. at time t
$y_S(t)$, $y_L(t)$, $y_R(t)$: longitudinal position of S, L, and R, resp. at time t
$V_S(t)$, $V_L(t)$, $V_R(t)$: speed of S, L, and R, resp. at time t
$S_L(t) = y_L(t) - y_S(t)$: headway between S and L at time t
$S_R(t) = y_S(t) - y_R(t)$: headway between S and R at time t

A study on Metro Manila jeepneys by Mitsuhata (1998) provides a data set of vehicle trajectory plots of jeepneys and other vehicles. The locus of points of vehicle position plotted every 0.1s is used in this study to demonstrate an objective assessment of the aggressiveness of drivers in Metro Manila. Vehicle position plots are used to calculate relative speeds and distance headways for jeepneys performing lane changes, which are then used to compute φ. The result of analysis is given in Figures 1 and 2. Result for Tokyo data, taken from a weaving section along Tokyo Metropolitan Expressway (Nakamura *et al.*, 1992) is superimposed over that of Metro Manila to allow comparison. The vertical axis represents cumulative share of sampled vehicles that have corresponding index values on the horizontal axis. The curve for Tokyo depicts aggressive lane changing behavior, according to Nakamura *et al.*, but the curve for Metro Manila reveals higher shares of drivers with very negative index values. This suggests an even more aggressive or more risky lane changing behavior.





Figures 1 (left) & 2 (right). Cumulative rate of vehicles for varying values of φ.
(Index φ is rate of change of distance headway, a measure of lane changing aggressiveness; Tokyo data from Nakamura *et al.*, 1992)

This brief analysis proves that driving behavior, especially that of the jeepney driver, is aggressive in Metro Manila and is a significant local phenomenon that must be given importance in building the simulation system.

3.2 Traffic phenomena at jeepney stops

Behavior of transit vehicles

The simulation system in this study includes the operation of bus and jeepney, with particular attention given to the latter's behavior. Past studies and video footages of traffic situation at transit stops enable a closer examination of the characteristic nature of jeepney behavior in the vicinity of transit stops. A descriptive summary of observations is given below.

<u>Characteristic behavior of jeepneys</u>:

1. If there are passengers wanting to alight from the jeepney, the jeepney stops according to the place indicated by the passenger or at a place where it is relatively convenient or meritorious for the driver to stop.
2. Jeepney approaches and stops near passengers who want to get on board.
3. In case there are many potential passengers waiting at the curbside, the jeepney will approach and prefer to stop near those relatively upstream. This seems to be the best position to maximize possibility of getting passengers and also so as not to lose potential passengers to jeepneys following behind.
4. Jeepneys crawl as they approach the loading and unloading area while seeking potential passengers.
5. When a bus is stopped in front, approaching jeepneys have a strong tendency to overtake and stop in front of the bus because the bus can obstruct the vision of driver and potential passengers. Also, the jeepney finds it difficult to depart after it has completed boarding and alighting operation from behind a dwelling bus.
6. On wider roads, jeepneys are often observed to dwell also on the lane adjacent to the curbside lane such that dwelling transit vehicles occupy the 2 outermost lanes.
7. Jeepneys tend to compete for potential passengers. This causes them to perform behaviors targeted to disturb passenger-seeking behavior of other jeepneys. For instance, a jeepney running on a lane adjacent to the curbside lane may suddenly change lane to get in front of a running jeepney on the curbside lane to get ahead and stop near waiting passengers first.
8. Jeepneys dwell and wait for passengers until filled to capacity. (Jeepneys normally dwell on-street since most transit stopping areas in Metro Manila are on-line or not provided with turnouts.)

Clearly, operation of jeepneys is different from conventional transit operation found in developed countries. It can be said that driver behavior is largely motivated by maximizing ridership to maximize profit since jeepney and bus companies in Metro Manila are owned and operated by the private sector. This motivation results in competition among jeepneys and helps explain their aggressive behavior on the road.

Buses and jeepneys are observed to behave similarly (also noted in Regidor & Sigua, 1995). Along "EDSA", the busiest major arterial in Metro Manila where most intra-city bus operation is concentrated, the same aggressive-passenger seeking behavior can be clearly observed. Difference with the jeepney is primarily due to its size and physical attributes (acceleration, turning radius, location of passenger doors, sitting capacity), which makes it less "agile" and performs more restricted movements compared to the jeepney. But the propensity for lateral movements, interaction with waiting passengers, competition with other transit vehicles, and motivation of drivers to maximize ridership are also behaviors attributable to buses.

Transit dwell time

The time it takes for a jeepney (and other transit vehicles) to dwell at the loading and unloading area includes passenger boarding time, alighting time, and waiting time for passengers. The U.S. Highway Capacity Manual (TRB, 2000) states, "dwell time is proportionate to the boarding and alighting volumes times the service time per passenger" (p. 14-5). Using video footage of jeepneys performing loading and unloading operation at a stop located just outside a shopping center in Metro Manila, number of passengers and boarding and alighting times is obtained. Simple linear correlation analysis proved that there is a strong relationship between number of alighting passengers and the alighting time (correlation coefficient = 0.909). However, the boarding time showed lower correlation with number of boarding passengers with correlation coefficient equal to 0.797. The explanation lies in how waiting passengers are actually scattered, as opposed to lined-up, on the sidewalk when a jeepney arrives. It is observed that it takes some time for passengers to approach the jeepney when boarding and the duration depends on their initial distance from the jeepney upon its arrival. This situation thus introduces some variance in the measured boarding times. Figure 3 shows the frequency distribution of the time difference between the instant of jeepney arrival and the time when the first passenger starts boarding the vehicle, but only for samples with no alighting passengers. Correlation analysis is again conducted, but this time between adjusted boarding times (original boarding times less approach time of first passenger for samples where adjustment is applicable) and number of boarding passengers. The correlation improved and is computed to be equal to 0.920, thus proving strong correlation between boarding time and number of passengers. Also, the analysis shows that the actual position of the waiting passenger and the jeepney affects total boarding time and consequently dwell time. Figure 3 also indirectly represents the distribution of passengers' waiting position along the curb.

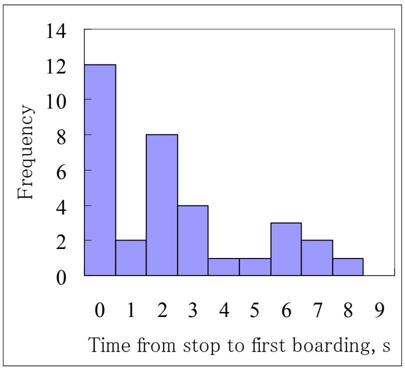


Figure 3. Frequency distribution of dwell time component
(Duration from instant of stopping to time of boarding of first passenger)

Interactions related to stopping behavior of jeepneys

The discussions above confirm that the jeepney's stopping behavior is influenced by other agents, namely (1) passengers waiting for transit rides at curbside, and (2) other transit vehicles running or operating near the subject jeepney. The jeepney, and these other agents interact with each other and cause mutual influence on each other's behavior. These interactions are modeled explicitly and included in the simulation system.

4. BUILDING THE SIMULATION SYSTEM

4.1 System features

The types of vehicle considered in the simulation system are normal car, heavy vehicle, jeepney, and bus. Recently, there is tendency for increased operation of the FX but for now it is assumed that its main operating behavior is similar with the jeepney and will be counted and treated as a jeepney. Passenger waiting on the curbside is also included as necessary agent and an algorithm that sets rules on its behavior and movement within the simulation space is constructed. The agents and related behaviors considered in building the simulation system are schematically shown in Figure 4.

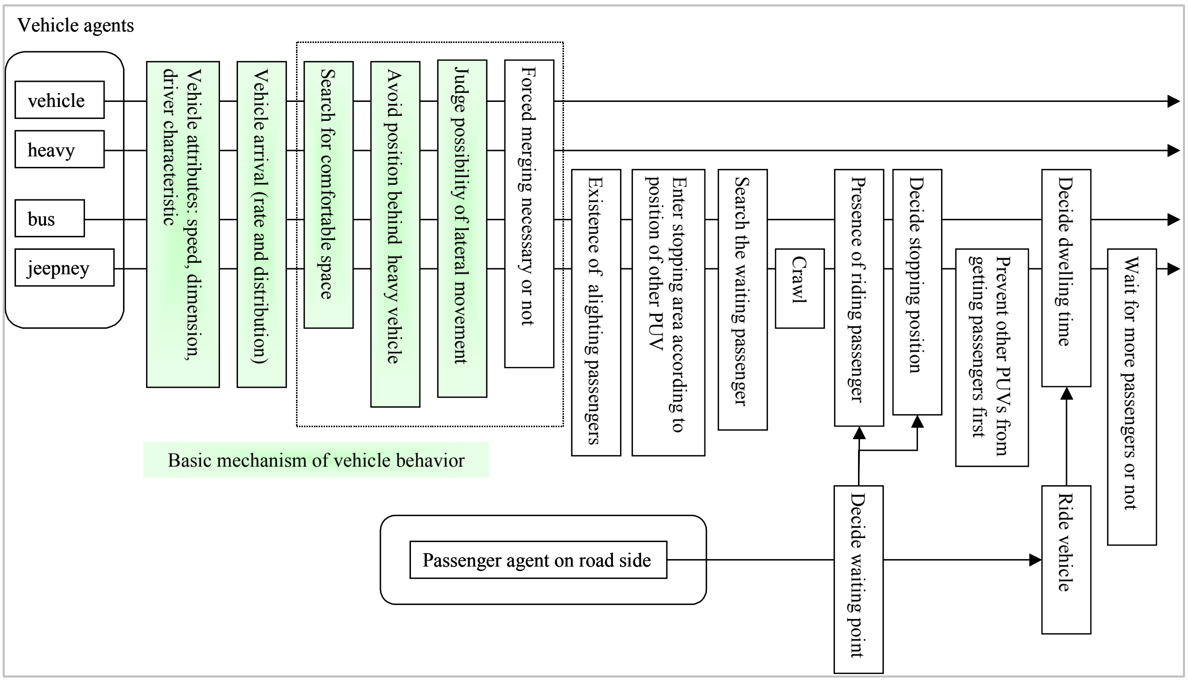


Figure 4. Related behavior of agents considered in the simulation system

The main features of this simulation system that makes it distinct from other traffic simulators are: (1) simulation of vehicle movement without regard for lanes (to reproduce the propensity for non-observance of lanes in Metro Manila), and (2) simulation of on-street stopping behavior of transit vehicle (jeepney, particularly), which dynamically and mutually interacts with passenger agents waiting at the curbside with its own movement algorithm running at the same time.

4.2 Concept of simulating vehicle movement without regard for lanes

In the vicinity of jeepney stops, vehicles are observed to move along without observing normal road lane configuration. This suggests that road capacity is decided not by lane number but by available usable road width. This is particularly evident, for example, when some transit vehicle is stopped on the curbside, on a nominal 2-lane road, and traffic is still able to pass by in two's even though there is only one lane left available. Table 2 gives a comparison of simulation elements with and without lane observance. The comparison shows that traffic simulation without lane observance requires more complex treatment of the elements considered in the model.

Table 2. Comparison of simulation elements with and without regard for lanes

Elements considered in model		Comparison of treatment/expression in the simulation	
		Not using lanes (Movement without regard for lanes)	Using lanes (Movement according to lanes)
Forward movement	Followed vehicle	Many possible front vehicles to "follow"	Subject vehicle follows front vehicle on same lane
	Side vehicle approach	Results in speed decrease	Vehicles run on fixed lanes so subject do not come near side vehicles
	Slip through	Necessary to consider	Not considered
Lateral movement	Target lateral position	There are practically an infinite number of choices	Judgment is only between current lane, or adjacent (left or right) lane
	Judgment of possibility to conduct side movement	Consider all related vehicles on the side that may affect the side movement (including road edge)	Consider only lead or lag vehicles on the adjacent lane

In this study, condition for traffic flow without regard for lanes is simulated using relative speeds and distances between a subject vehicle and the vehicle ahead, i.e., basic car-following concept is included. The car-following concept using distances between subject vehicle and front car as basic factor is employed in many traffic micro-simulators, but for this study, distances between the subject vehicle and side vehicles in the front vicinity are also considered. The behavior or action is based on the principle wherein a driver reduces speed upon sensing danger from getting too close with other vehicles, not only with the vehicle in front, but also with vehicles running beside. Table 3, obtained from a study in Japan by Ohara *et al.* (1996), shows the relationship between vehicle-to-vehicle side distance and forward speed. There is concern that this data may not be able to represent aggressive behavior in Metro Manila, but for now, after inspecting the original data source, it is assumed that the difference is slight and these values are adopted without modification for this study.

Table 3. Side distance & forward speed (Ohara *et al.*, 1996)

Side distance (cm)	Forward speed (km/h)
12.5	8.5
20.0	13.0
27.5	20.5
35.0	26.5
42.5	31.0
50.0	33.5
57.5	40.0
65.0	40.0

The concept of simulating vehicle movement without regard for lanes is roughly illustrated using Figure 5 for the vehicle labeled "subject". There are several possible choices for the subsequent behavior of "subject". The choice decision criterion is related to side vehicle distance and the expected forward speed. That is, from the various movement and car-following options, the option that promises the best forward speed is chosen. For example, for the case shown in Figure 5, "subject" first finds itself behind a stopped vehicle (say, jeepney). The first option is to follow the vehicle immediately in front, but that means a subsequent forward speed (V) equal to zero. Depending on the configuration of running cars at that instant (the time of decision making), "subject" will evaluate its options (based on side distances, available road width, forward distance, forward speed), so as to attain the best speed in the next time step. For the example shown, option 2 promises the best condition and "subject" performs the action. Reproduction of this non-observance of lane behavior with lateral movements requires a complex algorithm and is included as part of the main simulation program.

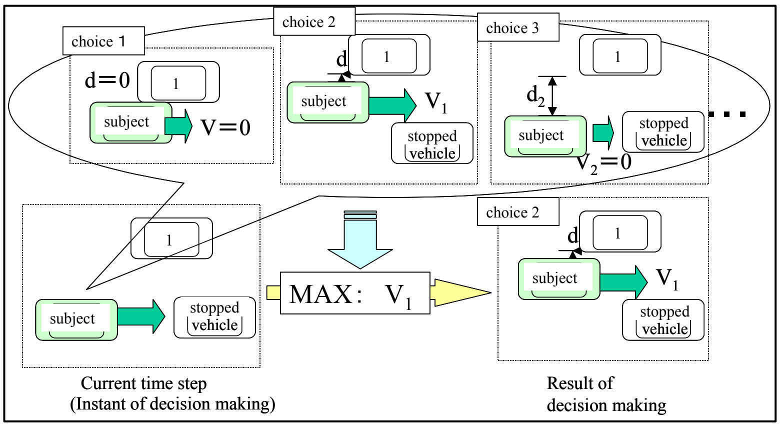


Figure 5. Illustration of mechanism for lateral movement

4.3 Concept of simulating transit vehicle stopping behavior

It is mentioned earlier that the stopping behavior of transit vehicles is a result of the mutual interaction or effects among several agents. This study makes use of multi-agent simulation as the method of expressing this dynamic and interactive behavior in the simulation space. The base mechanism employs the concept of "potential reward". (Although the discussion of stopping behavior in this section is illustrated using the jeepney, the logic is assumed to generally apply to the bus also.)

First, it is assumed that the underlying motivation for stopping, of say a jeepney, is to pick-up as many passengers as possible and fill-up the available seating capacity. The basic rule is that the jeepney gets reward if it is able to get passengers. Since each passenger represents potential reward, the jeepney approaches and is led to the waiting position of the passengers and consequently stops there. At any instant upon the approach of the jeepney, the road space offers several possible stopping positions and each position carries a "state value" defined in this study as an index that represents varying degrees of discounted potential reward depending on the jeepney's relative distance to the waiting passengers and presence of other competing transit vehicles. The state values on the road space guide the trajectory of the jeepney to the position where it eventually stops and boards passengers or gets the reward (see Figure 6). The related mathematical expressions for assigning "state value" are given as Eqns. 2 & 3.

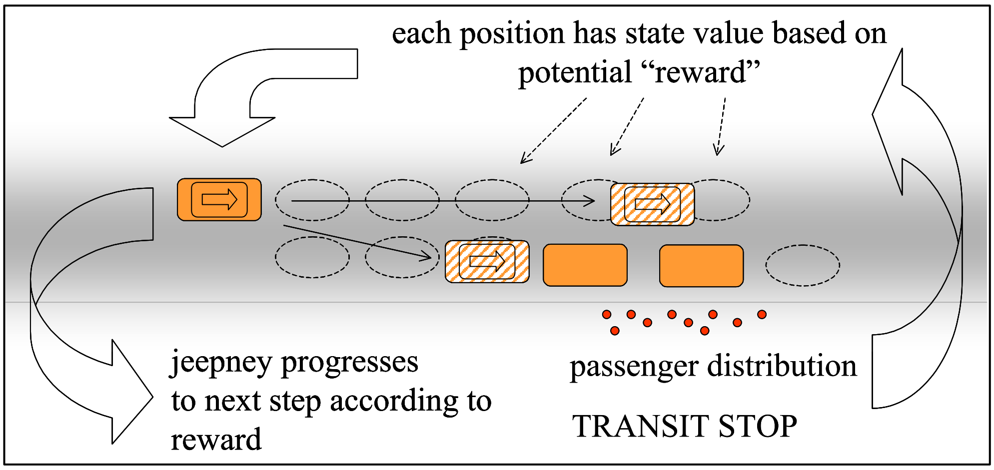


Figure 6. Illustration of potential reward and jeepney stopping behavior

$$StateValue_p = SV_{wp} * SV_{sc} * \alpha SV_{rc} \tag{2}$$

Where:
SV_{wp} : state value of stopping position, p, representing potential reward related to waiting passengers on the curbside
SV_{sc} : state value that captures the effect of other stopped transit vehicles (state value for positions immediately behind and front of an already stopped transit vehicle; this is to describe the aversion of stopping behind a bus, for example, or to represent the impossibility of stopping within some very near distance to a stopped vehicle)
SV_{rc} : discount rate to capture the effect of decreasing state value as distance from curbside increases
α : parameter (related to propensity to stop on other lanes adjacent to curbside; driver aggressiveness)

$$SV_{wp} = \sum_i \{(P * R)/d_i\} \tag{3}$$

Where:
i = ith passenger
R = reward of transit vehicle for getting passenger (arbitrary value, currently set to 10)
P = discount rate for uncertainty of successfully getting the passenger related to distance of transit vehicle from the waiting passenger (related to "far" and "near" sight distances)
d_i = straight line distance between possible stopping position and ith passenger

In evaluating state values for a transit vehicle for the current time step, the value of SV_{sc} is set to 0 for the road position and immediate vicinity of an already stopped transit vehicle while a value of 1 is set for all other positions around it. The variable SV_{rc} is intended to capture the effect of the attitude to resist stopping at positions in the way of running vehicles from behind which is affected by the expected arrival of the running vehicle and expected dwell time duration. This is particularly true for stopping positions away from the curbside lane. This parameter is very difficult to estimate and for now it cannot be set other than by calibration. At present this state value is set to 1 for all stopping positions between the curb and some fixed lateral distance from the curb (greater than the width of one lane), and a value less than 1 beyond it.

The concept of state values explained above also allows the reproduction of related behaviors such as the slowing down of jeepneys as they approach the stopping position while searching for passengers, and rivalry with other transit vehicles.

4.4 Structure of the Simulation Model

The system is built from the complex relationship among 6 sub-models and the program code is written using Visual C^{++}. Figure 7 shows the system structure with input-output flow relationship among the components. The system is built to simulate traffic conditions along a straight uni-directional road link with mid-block jeepney stop area induced at the point of generation of passenger demand. The default link length is 400m with a single passenger release point (Figure 8) but several passenger release points can be set and road widths can be varied. The release location represents main pedestrian egress of a traffic generator -- say a shopping center, or any location along the link where there is passenger demand, or even a fixed transit stop. This system allows evaluation of traffic flow conditions in the vicinity of mid-block transit stops and the effect of jeepney stopping behavior on traffic combined with the phenomena of general propensity of non-observance of lanes and lateral movements common in Metro Manila streets.

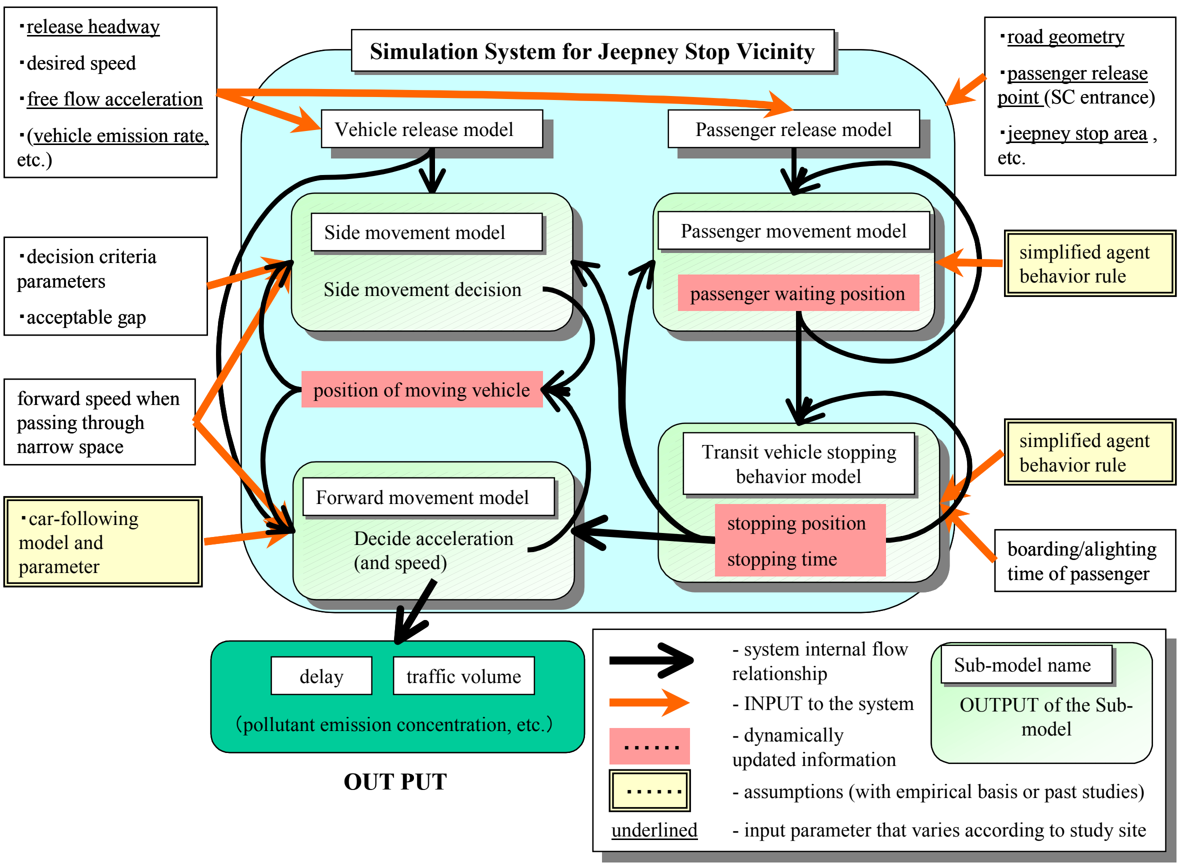


Figure 7. Structure of the simulation model system

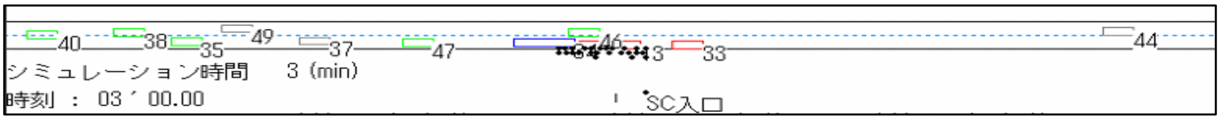


Figure 8. A screenshot of the simulation
(Black dots represent passengers)

5. SYSTEM VALIDATION

The simulation model includes a rough animation that can be viewed on the monitor while the program is running (Figure 8). Visual verification is considered satisfactory because animated vehicles and passengers seem to move and behave according to the algorithm logic. However, quantitative validation is required to definitely prove the adequacy of this system.

Testing the validity of traffic simulators is conducted in two stages: verification and validation. Verification includes checking program bugs to make it error-free, but more importantly, it must show that agents and simulation output behave according to the intended logic, concepts, or even theories prescribed in the algorithms. This stage does not require observed data (May, 1990); instead, hypothetical or virtual input data are used and simulation output are analyzed. Validation on the other hand seeks to ensure that the model is able to reproduce actual traffic conditions and thus requires comparison of simulation output and real world data.

Verification

For this study, the opted verification task is to check if the simulated traffic flow adheres to the established macroscopic relationship between volume and density ($Q=KV$) for uninterrupted traffic flow. The simulation subject is a link without transit stops, i.e., without the effect of transit vehicle stopping behavior. Following a procedure prescribed in a verification manual (JSTE, 2002), traffic demand is inputted in increasing increments and output volumes (Q, veh/hr) and corresponding densities (K, veh/km) are compiled and plotted (Figure 9). Artificial reproduction of flow to generate data plots at the congested region of the *Q-K* curve is quite difficult. It is attempted by positioning a stopped jeepney somewhere downstream at the curbside lane to emulate an obstruction to cause bottleneck, but reproduction of congested regime was unsatisfactory. As can be seen from the figure, the data plot on the congested side of the *Q-K* curve seems to deviate from the expected theoretical trend. Nevertheless, the result also indicates that the system has the potential to show the effect on capacity of a stopped vehicle on the curbside.

On the other hand, the *Q-K* plot for the free flow regime satisfactorily follows the desired trend, i.e., flow increasing with density. The maximum flow rate (taken to be the capacity) settles at about 4000 veh/hr. This value is close to the capacity of a 2-lane expressway according to the U.S. Highway Capacity Manual. Thus, the result of analysis is considered reasonable and helps prove the adequacy of the simulation system.

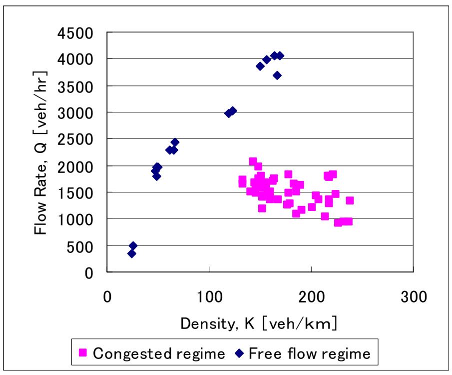


Figure 9. *Q-K* Plot

Validation

For the validation task, simulation result is compared with observed data. The subject of simulation is traffic along a section of arterial road with on-line transit stopping area in front of the main pedestrian entrance to a large shopping center (SC) in Metro Manila. Because of the stop location, passenger volume (or transit demand) is high due to the high development trip generation rate, and jeepneys and buses are observed to stop frequently, on street, to load or unload passengers. In the simulation, only the traffic direction near the SC is simulated, with a link length of 400m, 2-lanes, and passenger release point (SC entrance) set at x = 300m. There are many aspects and numerous traffic output parameters that need to be checked, but for this study, the validation items considered are (1) percentage of non-observance of lanes, and (2) transit vehicle dwell time.

Non-observance of lanes. From Section 3.1 above, it is recalled that traffic video survey results in a 14.3% frequency of non-observance of lanes. The same methodology is performed for the simulation output. The percentage of vehicles not traveling along nominally set lanes is found to be 17.0% and is considered quite close to the observed data. This analysis shows that the simulation system is able to replicate the propensity of non-observance of lanes, which is a very significant phenomenon in Metro Manila traffic.

Dwell time. The dwell time of transit vehicles in Metro Manila is the sum of passenger boarding and alighting times, and some additional waiting time. The waiting time can be further divided into time spent by drivers to wait for more passengers to fill up capacity, and some time duration from the instant the vehicle stops and the instant the first passenger boards. This latter time duration is the subject of validation task for transit dwell time. This particular component of dwell time is used as evaluation parameter because it also implicitly describes the distribution of passenger waiting positions.

Figure 10 shows the frequency distribution of this dwell time component for both observed and simulated values. The observed data is the same as in Figure 3 but this time shown in the form of frequency rate distribution using a line graph. The sample size of observed data is quite small and introduces some concern in making a strict comparison. However, it can be seen that the simulation system is able to reproduce a similar distribution to that observed. This suggests that the system is successful in reproducing transit dwell times that is affected by passenger waiting distribution, and also implicitly shows the interaction between the two agents, as prescribed in the program algorithms.

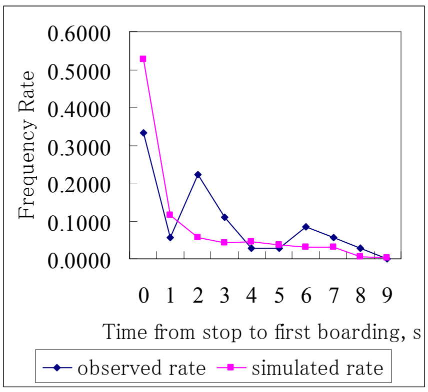


Figure 10. Comparison of observed and simulated dwell time component
(Duration from instant of stopping to time of boarding of first passenger)

6. CONCLUSION

In this study, traffic phenomena occurring in the vicinity of jeepney stops are systematically discussed and examined. The knowledge serves as basis in creating algorithms and building a simulation system that seeks to reproduce (1) traffic flow characterized by propensity of non-observance of lanes, and (2) jeepney stopping behavior that considers the mutual influence and interaction with waiting passengers and other transit vehicles. The built simulation system is able to reproduce these phenomena and this feature makes it distinct from other microscopic traffic simulators.

System validation is limited primarily due to scarcity of data. Because of this, further and more comprehensive validation is part of future research. However, the result of limited validation work done for this paper suggests that the designed algorithms aimed at reproducing jeepney and passenger behavior are sound. The intended future application of the simulation model is to serve as a tool for evaluating the effect of transit vehicles on traffic and evaluating policies related to site impact analysis.

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