AN ESTIMATION OF PASSENGER CAR EQUIVALENT OF MOTORBIKES

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ABSTRACT
Much research has been conducted on trying to solve traffic problems and applied successfully in many developed countries where the car is the main transport mode. However, it has not been effective in most developing countries where the motorbike, rather than the car, is the main transport vehicle. This paper estimates the passenger car equivalent of motorbikes under simulation analysis. Simulation scenarios are constructed and run, and the results are analyzed to determine that factor. The research shows that the passenger car equivalent of motorbikes depends on traffic conditions. The factor is expected as a useful parameter when applying traffic research in developing countries.

KEY WORDS
Mixed traffic system, Homogeneous traffic system, Simulation analysis, Passenger car equivalent of motorbikes

1. Introduction

Traffic systems particularly in developing countries are completely different from those in developed countries, where the motorbike is the main transport form rather than the car, so traffic systems' behaviors are distinct. Rather than fully complying with the traffic regulations, vehicles are also guided by nature rules. Together with other characteristics, traffic systems in developing countries are complicated. As in developed countries, traffic issues are interesting research topics and challenges for both the governments and researchers.

Many research models have been efficiently applied. Traffic flow theories including both macroscopic and a microscopic treatment are intended to provide an understanding of the phenomena relative to the movement of individual vehicles along a highway. Other theories about queuing and delays at isolated intersections have been constructed to discuss the effect of isolated intersections on the delay to drivers. For reasons of safety and avoiding the coincidence of two cars occupying the same space at the same time, a traffic control theory was presented. Other traffic theories such as traffic generation, distribution, and assignment have been introduced [1].

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An agent-based approach used to design a Transportation Regulation Support System (TRSS) is able to monitor the network activity under normal conditions and to automatically adjust to the environment changes by proposing feasible solutions in order to optimize the traffic flow [2]. To examine the effects of vehicle policy intervention on urban development and population, GDP and environment aspects, a system dynamics approach based on the cause-and-effect analysis and feedback loop structure was proposed [3]. To reduce infrastructure investment, a single lane for traffic in two directions is constructed by using Automatic Guided Vehicles [4].

In addition, many traffic simulations have been developed and efficiently used. The CORSIM, a microscopic traffic simulation model, has been constructed and used mainly in the U.S., which has specific strengths that assist in the modeling of complicated geometry conditions, to simulate different traffic conditions, account for the interactions between different components of networks, interface with external control logic and program, and model time-varying traffic and control conditions. Furthermore, many new traffic simulations are useful tools to support traffic operation analysis such as INTERGATION, VISSIM, MITSIM, WATSIM, PARAMICS, and TRANSIMS [5].

Although the aforementioned models have been successfully applied in developed countries such as France [2], Netherlands [4] and USA [5] and the modern cities as Dalian, China [3], they are unlikely to give reliable results if absolutely applied to the traffic systems in developing countries. The passenger car is usually used as one of the important indexes of the traffic systems. Rarely research has been done on the passenger motorbike, while it is the primary transport mode in most of developing countries. For example in Viet Nam, according to the Vietnamese Traffic and Public Works Service (2007), about 21.72 million individual motorbikes were registered in 2007, in a population of 81 million, compared with only 1.11 million cars. Therefore, for application in developing countries in general further considerations and adjustments need to be investigated.

In this paper, the passenger car equivalent of motorbikes is estimated under simulation analysis, where a simulation model for the mixed traffic system [6] is used to support. For this estimation, suitable simulation scenarios are generated. Analyses are performed based on simulation results. The passenger car equivalent could be used as a referent factor to convert the number of motorbikes to that of car and vice versa. It supports the more convenient determination of alternatives to improve traffic systems in developing countries. Finally, some suggestions and conclusions are proposed.

2. Methodology

The system considers two situations. The first system comprises 100% cars and 100% motorbikes that are analyzed separately. Two simulation model groups are developed, in which one is used to simulate only the cars' behaviors and the other only the motorbikes'. Based on the simulation results, the system's parameters in individual situations, the relations among the system's factors, and the system's saturated conditions are determined. Finally, based on comparisons between two cases, an estimation of passenger motorbikes equivalent of a car is done in the homologous traffic system.

The other situation considers a mixture of traffic (car and motorbike) on the road. The interaction between two transport modes is considered. Actually, the ratio between them is changed according to the simulation scenarios under the system's saturated conditions. The simulation results are recorded and analyzed to determine that factor.

2.1 Input Data

A set of experiments are constructed on a stretch of road, as shown in Figure 1. The 8-meter wide, two-lane road comprises three segments, in which vehicles are generated in the first 100m-long segment as a warm-up segment, the main physical part of the system is the second 500m-long segment, and the final 100m-long segment is used to release vehicles. The physical system is coded and converted into a part of the simulation data file, which is a fixed-data element of simulation scenarios.

Another unchangeable component is vehicles' physical parameters. When a vehicle travels on the road, from the top-down view it occupies an area, so in this simulation program each vehicle is represented by an appropriately sized rectangular. Therefore, the simulation model is modeled as a 2D one. Each vehicle has its own velocity and acceleration. The maximum velocity differs not only between cars and motorbikes, but also among the same vehicles. These characteristics are the main reasons for the conflictions among the entities in the system. All the relative information is shown in Table 1.

Table 1: Vehicles' Parameters

	Physical information (m)		Velocity (km/h)			Acceleration (m/s^2)
	Length	Width	$Vmax_a$	$Vmax_b$	Vmed	
Car	4	1.8	40	80	50	2.5
Motor	2	0.8	30	60	40	3

The maximum speed is modeled as drawn from a uniform distribution in the range $Vmax_a$ to $Vmax_b$. In addition, the initial speed follows a normal distribution, in which Vmed is the mean of population. Furthermore, the Poisson distribution is used to generate vehicles. In this paper, its mean, the number of vehicle entering the system per minute, depends on the scenarios, which is called the expected volume factor.

2.2 An Overview of Simulation Model

Many logic models have been applied to simulate driver-vehicle-units (DVUs) behaviors, such as car-following, free acceleration, lane-changing, direction-changing, stop-run, and intersection-conflict models [6]. Especially, the lane-changing approach usually used to simulate passenger car is modified to simulate the passenger motorbike. It is called as sub-lane changing approach, in which a sub-lane is a virtual lane on the road. Motorbikes can occupy any lateral position across the carriageways instead of traveling within real lanes, so they can move to one or two sub-lane(s) either on the left or the right hand side, while cars have to change to the next real lane on the left hand side. Although moving to the right side or changing more than one sub-lane to overtake another is illegal, it is ubiquitous. Priorities of lane usage are denoted from one to four, in decreasing order of common priority, which is called as flex-passing rules as shown on the Figure 2. In addition, motorbikes usually move in virtual groups. The sharp, speed and quantity of DVUs of the groups are changed usually and depends on the lead vehicle(s) and DVUs behaviors in the groups.

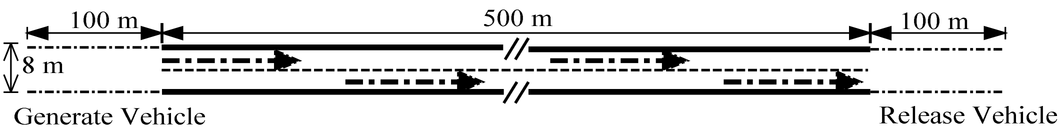

Figure 1: Physical Simulation System

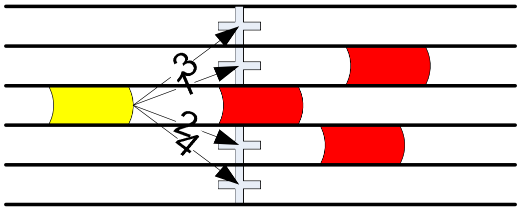

Figure 2: Flex-Passing Rules on Virtual Lanes

Some factors or indexes such as Volume IN, Volume OUT, Average Speed, and Density Index are used to validate the simulation model and evaluate the simulation results. These factors are recorded directly or indirectly through parameters obtained from counter machines set up at all inputs and outputs of roads. Among these factors, Volume IN (VI_{ij} - vehicles/minute) is the average number of vehicles type i^{th} travelling into the system at the road j^{th}, Volume OUT (VO_{ij} - vehicles/minute) is the average number of vehicles type i^{th} exiting the system at road j^{th}, and the Average Speed is determined through vehicle's travelled distance and time. The density of traffic used to evaluate the system's "busy level" is determined by using a formula provided by Gazis (2002) [1] as shown in equation (1).

$$\text{Density} = \frac{\text{Volume OUT}}{\text{Average Speed}} \qquad (1)$$

The other factor is the Utility factor, in percentage, which expresses the system's utility. It is evaluated by comparing with the highest density level or system's capacity for each homogeneous situation. Actually, the traffic states on the road section are determined by the simulation settings such as warm-up time and other conditions.

2.3 Experiments

Simulation scenarios are built up and grouped into three main groups according to the simulation's primary purposes. Group 1 considers the case with 100% cars traveling in the system. The number of vehicles entering the system increases up to the saturated point, at approximately 94 vehicles per minute. The second group considers that case with 100% motorbikes operating in the system. Similarly with the previous case, the number of entities entering the system increases up to the saturated point too, at approximately 540 motorbikes per minute. After determining the saturated points in both cases, the last main group is considered under the saturated conditions with mixed traffic systems.

Actually, the ratio between cars and motorbikes is changed by different simulation scenarios, but two methods are used to ensure that the system operates at saturated conditions. In the first way, the number of cars is generated at high levels above the saturated point and then the number of motorbikes entering the system increases. In the second way, the number of motorbikes entering the system is maintained above the saturated point, and the number of cars entering the system increases.

3. Analysis

In the first situation with 100% cars, the system obtains the highest "busy level", at approximately 281.10 cars per kilometer, at which its average speed is reduced to the low level at about 19.05 kilometers per hour. After reaching the saturated point, the system oscillates around it at high "busy levels". The system's serving capacity is shown as equation (2),

$$\begin{aligned} y_1 = f_1(x) &= -8325.8x^6 + 25826x^5 - 28916x^4 + 14251x^3 \\ &\quad - 4075.2x^2 + 1797.1x - 25.235 \\ &\quad \forall x \in [0,1],\ y_1 > 0 \end{aligned} \qquad (2)$$

where, y_1: The number of motorbikes entering the system per minute, in vehicles per minute.
x: System's utility, in percentage

In the other one with 100% motorbikes, similarly, after determining the system's saturated conditions and system's utility, the interrelation between the Volume IN factor and system utility factor is fitted as equation (3). As shown on the Figure 3, both systems seem stable when their utility factors reach around 60 percent. Before that point, although two factors increase simultaneously, the slope of motorbike curve is larger than another one.

$$\begin{aligned} y_2 = f_2(x) &= -2351.7x^6 + 7823x^5 - 9727.8x^4 + 5569.1x^3 \\ &\quad - 1582.5x^2 + 366.32x - 2.829 \\ &\quad \forall x \in [0,1],\ y_2 > 0 \end{aligned} \qquad (3)$$

where, y_2: The number of cars entering the system per minute, in vehicles per minute.

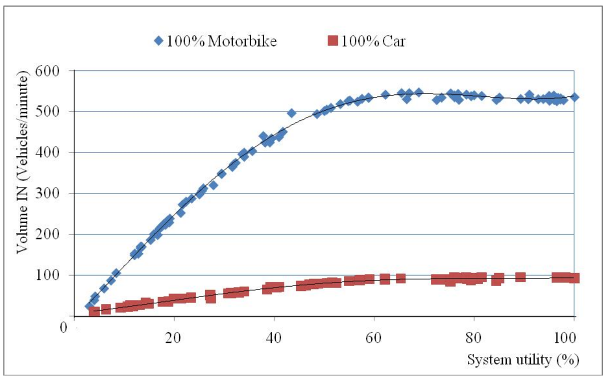

Figure 3: Interrelations of Volume IN Factor and System Utility Factor in Homogeneous Case

Based on the interrelations among the system's factors in both situations, the passenger car equivalent of motorbikes is estimated at each different system utility as in equation (4). The system serves an equivalent quantity between the cars and motorbikes, and the ratio between them at each system utility is concluded from the equations (2), (3) and (4) and shown on Figure 4.

The equivalent factor increases rapidly when the system utility factor is lower than 20 percent. It reaches above 6.5 when the system utility factor ranges from 20 percent to 40 percent. In the other stage, the conversion ratio seems to be slightly reduced,

$$f(x) = \left|\frac{y_1}{y_2}\right| = \left|\frac{f_1(x)}{f_2(x)}\right| \qquad \forall x \in [0,1] \qquad (4)$$

where:

y_1 : The number of motorbikes entering the system per minute, in vehicles per minute.

y_2 : The number of cars entering the system per minute, in vehicles per minute.

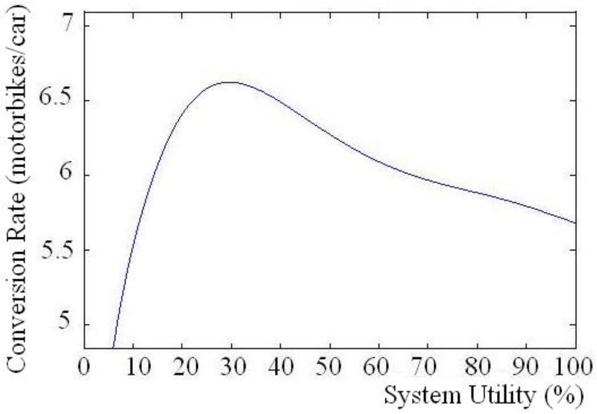

Figure 4: The Passenger Car Equivalent of Motorbikes in Homogeneous Case

In the mixed traffic case, cars and motorbikes travel in the same system, and thus affect together. As mentioned previously, the system is only considered at the high "busy level" and there are two ways to generate the saturated conditions. In the first one, the cars make the system operate at high level and the number of motorbikes is increased. The interrelations between the Volume IN factor and the system utility factor of two populations are determined as shown on Figure 5. Two curves are inversed together because cars and motorbikes travel in the same system. Actually, when the number of motorbikes increases, that of cars decreases. The reduction of cars in quantity and system's utility, simultaneously, follows an exponential distribution as equation (5),

$$y_2 = f_2(x_2) = 1.9894e^{4.0484x_2} \qquad \forall x_2 \in [0,1] \qquad (5)$$

where, x_2 : Car's utility, in percentage

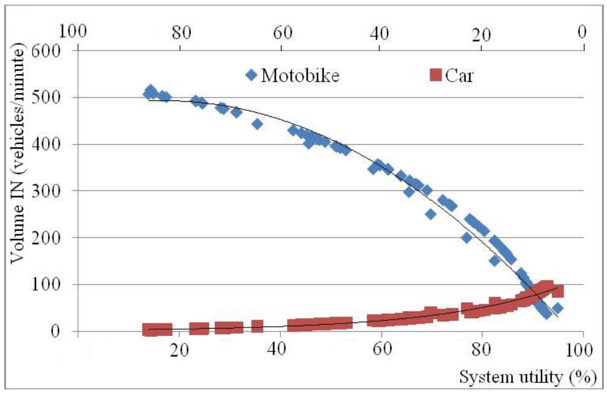

Figure 5: Volume IN –System Utility Relation in a Mixed Traffic System

In addition, the relation of the Volume IN factors between two populations is inverted and fitted as equation (6). It follows a poly-function instead of a linear one as shown on the Figure 6. The changeable ratio between two populations is withdrawn from the equation (6) and shown as equation (7). The passenger car equivalent of motorbikes depends on the system's car utility. It is determined from the equations (5) and (7) and shown on the Figure 7.

$$y_1 = 0.0372y_2^2 - 8.7581y_2 + 533.74 \qquad (6)$$

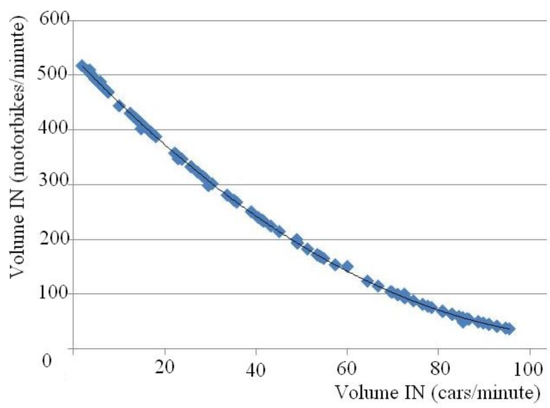

Figure 6: The Volume IN Inversion of Two Populations in the Mixed Traffic System

$$\left|\frac{dy_1}{dy_2}\right| = \left|0.0744y_2 - 8.7581\right| \qquad (7)$$

The conversion rate increases when the car's utility in the system decreases. The curve increases so fast when the car's utility reduces from 100 percent to around 50 percent. In another stage, it slowly increases from around 8 to 8.6.

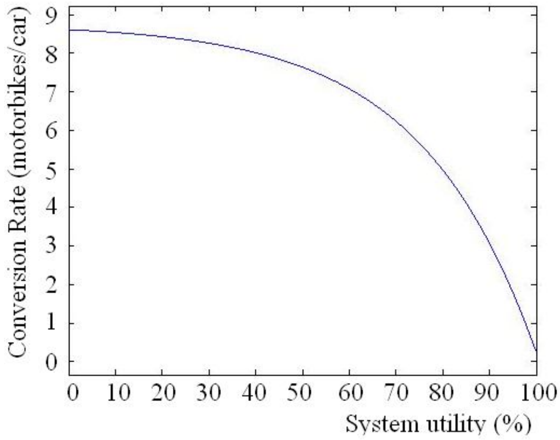

Figure 7: The Passenger Car Equivalent of Motorbikes in Mixed Case with Car Domination

Flexibility, a special characteristic of motorbikes, allows them to travel in unfixed lanes, easily change to a suitable lane, and exhibit high acceleration because small size is its advantage. In addition, car's speed is adjusted by the number of motorbikes traveling in the system, so that the affected level increases synchronously. Therefore, when car's utility does not dominate motorbike's one, lower than 50 percent, the conversion rate increases slightly although the car's utility decreased in the same rate.

When the system's saturated conditions are generated by motorbikes instead of cars, their effects on the system are clearly shown. Although the number of cars entering the system is increased, the other factors of both populations still vary around. The interrelations of Volume IN factor and system utility factor of two populations are shown as on the Figure 8, where two populations are stable in the mixed system with motorbike domination. Each population is shown more clearly in the Figure 9 and Figure 10 for car population and motorbike one in respectively. The conversion rate is determined based on the variations of both populations as shown on the Figure 11. From the simulation results the authors conclude that the passenger car equivalent of motorbikes follows a normal distribution with mean = 23.279 and standard deviation = 1.539.

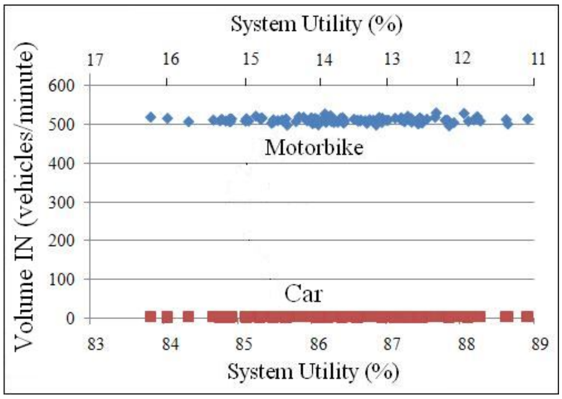

Figure 8: Two Populations in the Mixed System at Saturated Conditions with Motorbike Domination

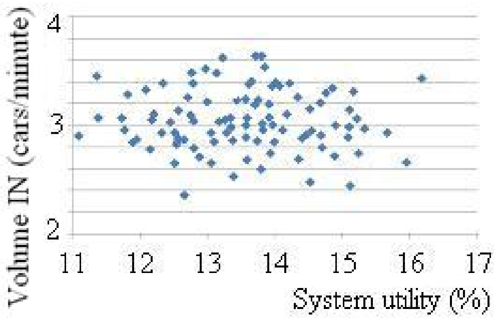

Figure 9: Car Population in the Mixed System at Saturated Conditions with Motorbike Domination

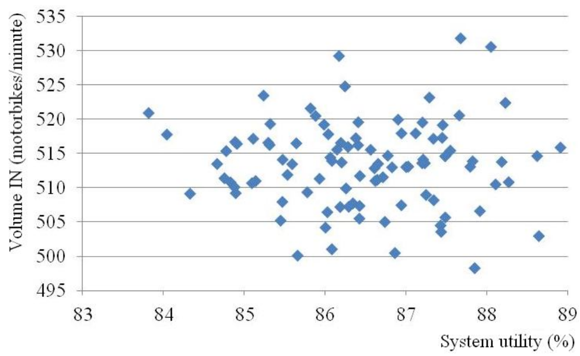

Figure 10: Motorbike population in the mixed system at saturated conditions with motorbike domination

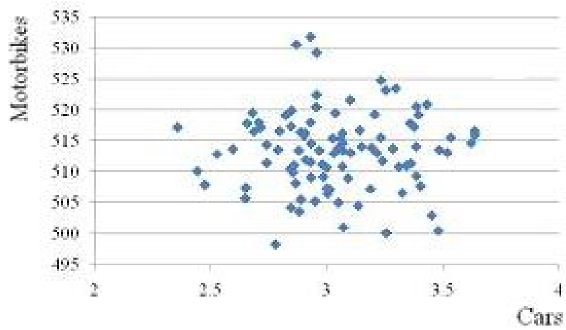

Figure 11: The Passenger Cars Equivalent of Motorbikes in Mixed Case at Saturated Conditions with Motorbike Domination

4. Conclusions

The passenger car equivalent of motorbikes was determined from simulation results. It depends on traffic conditions that whether the traffic system is homogeneous or mixed or how much car's ratio in the mixed system is. The results will be useful for many research applications in developing countries. Mathematical models and useful technologies that facilitate the efficient solution and improvement of traffic problems in developed countries where the car is the main transport mode can be applied in analogous ways.

For example, considering the underdeveloped infrastructure of developing countries and comparing the ratio between cars and motorbikes on the same system, suitable policies include limiting the number of cars travelling in the traffic system, and replacing the car with the motorbike as the main transport vehicle.

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