Macroscopic Flow Models of State Highway Midblocks under Mixed Traffic Flow Conditions: Ramon Magsaysay Boulevard Case Study

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Abstract. Macroscopic flow modelling has been fundamentally used to characterize and predict the traffic flow parameters of a continuous road utilizing the analogy for one-dimensional fluid flow. In the Philippines, Ramon Magsaysay Boulevard is a major arterial road that links Manila City to various important cities in the Metropolis. Due to its noticeable deteriorating performance in addressing the increasing traffic flow demand, this work investigated the corridor capacity and characterized the key traffic elements along the major mid blocks using Greenshields model. It is assumed that road users behave uniformly and continuously distributed over the highway to choose a path to minimize their total travel time based on instantaneous traffic information. Investigation shows volume demands exceeding the design traffic capacities equivalent to 0.7429, 1.7959, 0.7226, and 1.4726 VCR ratios.

1. Introduction

The macroscopic flow of models that are currently used and further utilized today originated from the fundamental assumption that there is a degree of relationship among vehicle positions and their velocities [1]. Elementary principles of fluid motion for one-dimensional flow such as the equation of continuity and the equation of motion have been adapted to traffic modelling, arriving with the general equation

\[
\frac{du}{dk} = -ck^{n-1} \tag{1}
\]

where

\begin{align*}
    u & = \text{speed} \\
    k & = \text{density} \\
    c, n & = \text{arbitrary constants.}
\end{align*}

On the other hand, Greenshields [2], after assessment of recorded vehicle speeds and densities along a continuous road, conjectured that there is a linear relationship between the two traffic variables, shown as

\[
u = u_f \left[ 1 - \frac{k}{k_{jam}} \right] \tag{2}
\]

where

\begin{align*}
    u_f & = \text{free-flow speed} \\
    k_{jam} & = \text{jam density.}
\end{align*}
This clearly suggests that the density-flow relationship would in turn be parabolic. The speeds were obtained by locating the position of vehicles from two or more pictures taken at short time intervals. It can also be perceived that this formula can be directly obtained from (1) by substituting \( n=1 \) and applying the boundary conditions for the case of free-flow velocity and jam density. Frequently, the density-flow scatter plots are widely scattered due to non-equilibrium traffic condition [1]. Zhang proposed that there should be a distinction in acceleration and equilibrium flow with the speed-density relation; over the entire road length speed and density remains constant [3]. Plots not satisfying this criterion must be discarded from the graph.

Meanwhile, Ramon Magsaysay Boulevard is an eight-lane divided arterial road that connects Nagtahan interchange, A.H. Lacson Avenue, and Legarda Street, Manila City in the west wing up to G. Araneta Avenue, Quezon City and Aurora Boulevard, San Juan City in the east wing. In its entire length, the route is traversed by Light Rail Transit Line 2, with which two of its significant stations are located. Total travel demand along this route is high because it is a highly urbanized area, and various institutions are located nearby the corridor. Thus, the road is noticeably deteriorating in addressing traffic flow performance as time progresses.

This paper aims to evaluate the current traffic flow capacity of Ramon Magsaysay Boulevard utilizing the fundamental macroscopic model (Greenshields model). Finally, the Levels of Service of the selected mid blocks will be determined according to the guidelines stipulated in Highway Capacity Manual 2000.

2. Methodologies
This study aims to evaluate the traffic flow performance of Ramon Magsaysay Boulevard using macroscopic flow modelling. Fundamental traffic flow parameters utilized in this study are detailed below.

2.1 Volume studies
Traffic volume is the most fundamental data needed for the study of traffic flow. Volume studies correspond to the number of vehicles passing thru a point within the area of study in relation to time; hence, the data shall be expressed in the number of vehicles with respect to time.

The volumes to be gathered by the researchers utilizing Cordon counts are as follows: 1) the average daily traffic (ADT), which corresponds to the actual demand for service by the road, 2) hourly traffic and short term (15-minute) count to estimate the maximum flow rate and to identify the peak hour volumes. In terms of the time of the study, this work shall perform the count during 7 AM to 9 AM, and 5 PM to 7 PM to represent the very high level of traffic volume, and short counts of one hour with 15 minute-interval to analyze peak hour volumes. Figure 1 illustrates the data collection performed during the study. Situations that would cause abnormal conditions, such as holidays or fiestas, bad weather conditions, or demonstrations shall not be allowed in the study [4]. It is important to consider the passenger car equivalent factors (PCEF) depending on the type of vehicles entering the study section as stipulated in the Department of Public Works and Highways (DPWH) Highway Capacity Manual [5].

2.2 Spot speed studies
Like volume studies, situations that would cause abnormal conditions with the traffic flow shall also not be avoided during spot speed studies. The ideal duration for this study shall be around one hour. This paper shall use the manual method, also known as “trap length method,” because it is the most efficient to execute among all methods. In this technique, two lines, 30 meters apart, shall be drawn transversely on the pavement. A stopwatch is then used by the field researcher to measure the “elapsed time” of the vehicle within the trap. This procedure shall be done 30 times for the analysis and presentation of the spot speeds. Furthermore, to avoid bias in sampling systematic random sampling shall be employed, wherein every nth vehicle represents the whole spot speeds within that closed area for that specific time range alone.
2.3 Analysis and presentation of traffic data

Using the data obtained from the quantitative studies (volume studies, spot speeds, and density), fundamental traffic flow parameters can be readily fitted in graphs. For speed-density relationship along mid blocks, simple linear regression modelling can be used using the equations.

\[ u = \frac{\sum k_i u_i - n \bar{u}}{\sum k_i^2 - n \bar{k}^2} \quad \text{and} \]
\[ a = \bar{u} - b \bar{k} \]

Moreover, the Levels of service can also be determined at this point base on the design capacity assigned for this type of road.

3. Results and discussion

Figure 2 shows the histogram of vehicle speeds observed at the first eastbound midblock. The arithmetic means speed is 25.0 kph with a standard deviation of 9.33 kph, showing a widely scattered speed data. In addition, Figure 3 shows the cumulative distribution of frequencies at midblock 1. It can be depicted that the 50th percentile speed representing median is 21.64 kph, while the modal speed is 29.0 kph. Finally, the speed limit that can be imposed given these traffic conditions is 31.89 kph, which is the 85th percentile speed.

Applying the principles used and developed in Greenshields model, the speed-density relationship of at midblock 1 is

\[ u = -0.1066x + 31.2855 \]

With an R squared of 0.698749, depicting low correlation. Plots not satisfying equilibrium should not be considered in the relationship. Figure 4 shows the abovementioned relationship.
On the other hand, Figure 5 shows the histogram of vehicle speeds observed at the second eastbound midblock. The time-mean speed for this road section is 20.67 kph with a standard deviation of 9.75 kph. The figure shows irregularities in spikes within the region of lower speeds, suggesting that vehicle arrivals using stochastic methods cannot be applied here. Furthermore, Figure 6 displays the cumulative distribution of frequencies at midblock 2. It can be depicted that the 50th percentile speed representing median is 18.41 kph, while the modal speed is 24.0 kph. Finally, the speed limit that can be imposed given these traffic conditions is 28.04 kph.

The relationship of density and speed when applying Greenshields model again is

\[ u = -0.097k + 34.249 \]

with an R squared value of 0.716, indicating a low correlation between the parameters. Figure 7 illustrates this relationship.

For the westbound direction of flow, Figure 8 shows the histogram of vehicle speeds observed at the first midblock. The arithmetic mean speed in this section is 12.17 kph with a standard deviation of 9.54 kph. It can be observed that there should have been a normal curve plot with its peak approximately at 14.5 kph, but there is an odd frequency for middle-class speed of 4.5 kph. In addition, Figure 9 displays the cumulative distribution of frequencies. It can be depicted that the 50th percentile speed representing median is 6.26 kph, while the modal speed is 4.5 kph. The speed limit that can be imposed given these traffic conditions is 19.85 kph; however, this value is so small that imposing this speed limit can be quite unimportant.
Greenshields model of speed-density relationship for this midblock is

\[ u = -0.107k + 31.278 \]  

yielding a correlation coefficient of 0.607082, denoting a low correlation of plots. Figure 10 shows the relationship.
Finally, Figure 11 illustrates the histogram of vehicle speeds observed at the second midblock westbound direction. The arithmetic mean speed corresponding in this section is 25.63 kph with a standard deviation of 9.85 kph. It can be observed too that the frequency shows a stochastic distribution of vehicle speeds with its modal speed at 27.5 kph. Figure 12 displays the cumulative distribution of frequencies with the 50th percentile speed of 22.83 kph. The speed limit that can be imposed given these traffic conditions is 32.57 kph.

Applying the principles used and developed in Greenshields model, the speed-density relationship of at midblock 1 is

\[ u = -0.239k + 48.438 \] (8)
with an R squared of 0.712, also depicting low correlation.

The maximum sustainable flow rate at which vehicles can be expected to traverse a point during a certain period of time for four-lane two-way divided highway in the Philippines is 3,400 veh/hr. Based on the recorded flow rates at 15-minute time intervals, the flow rate at midblock 1 for eastbound and westbound are 2,526 veh/hr and 2,457 veh/hr. On the other hand, the recorded flow rates for midblock 2 for eastbound and westbound are 6,106 veh/hr and 5,007 veh/hr, respectively. Table 1 shows the levels of service at the mid blocks.

| Midblock | Volume  | Capacity | LOS |
|----------|---------|----------|-----|
| 1 (Eastbound) | 2,526 | 3,400 | D |
| 2 (Eastbound) | 6,106 | 3,400 | F |
| 1 (Westbound) | 2,457 | 3,400 | D |
| 2 (Westbound) | 5,007 | 3,400 | F |

4. Conclusions
Ramon Magsaysay Boulevard’s important mid blocks traffic flow capacities were investigated using Greenshields model. The following conclusions can be drawn from the results:

- The actual traffic flow variables and capacity of Ramon Magsaysay Boulevard is not efficiently capable in sustaining the vehicular flow demand passing through it. Very low levels of service directly affect the ridership, transportation cost, and comfortability of the road users. Additional traffic measures must be implemented to decongest the thoroughfare.
- High traffic congestion in the mid blocks directly affected the consistency of the principles used in macroscopic flow modelling. Equilibrium flows and accelerations must be distinguished evidently with the corresponding speed and density relationships in order to acquire more correct models.
- Most of the diagrams constituted a widely scattered set of points. Standard deviations of speeds ranged around ±9 kph showing a need for the more accurate methodology of recording data. Moreover, several factors were neglected in the analysis such as road friction factor, obstructions of traffic regulations, lane changing of some drivers, to name a few. Accuracy would increase significantly if these would be addressed in the future researches.

5. References
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