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Modelling and Pattern Data Analysis of Vehicle Density in Pasupati Bridge Bandung City

[1]Mochamad Vicky Ghani Aziz, [1]Armein Z.R. Langi, [1]Ary Setijadi Prihatmanto and [2]Rifki Wijaya
[1]School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Bandung, Indonesia
[2]Department of Computer Engineering, Faculty of Electrical Engineering, Telkom University, Bandung, Indonesia

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Corresponding Author:
Mochamad Vicky Ghani Aziz
School of Electrical Engineering and Informatics, Institut Teknologi Bandung, Bandung, Indonesia

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Abstract: Bandung is a city with a population of 2.5 million people. In the city there is human mobilization in time and in certain amount. Population growth has a very close relationship with the growth of vehicles within the city of Bandung. The population growth model is depicted in a mathematical equation that is closely related to the vehicle growth model in Bandung city. The renewed population and vehicle growth model are the material for making a traffic engineering after it has been made predictive analysis. A case study was conducted at the Pasupati Bridge, one of the most densely populated places in the city of Bandung. Data on the number of passing vehicles taken within the span of 3 months using CCTV. The congestion solution is offered in the form of vehicle density prediction analysis and a hybrid-multi-scale traffic simulator. This hybrid-multi-scale traffic simulator is a vehicle simulator that describes the almost real-time current conditions.

INTRODUCTION

Bandung city as the Capital of West Java Province has its own attraction for people to live in the city. The population of Bandung city increased every year due to the birth rate and population movement with various objectives such as education, trade and improvement of the family economy. Until 2018 the population of Bandung city reached 2,503,708 people with population growth rate of 0.88% and population density reached 14,964 inhabitants km^{-2}. Increasing the number of people who are not offset by improving the quality of service will lead to problems in the field of transportation, especially, congestion.

Traffic congestion is one of the biggest problems in a city today. Not only affect the economic aspects in urban areas but also affect the psychology of the community and the level of vehicle emissions in urban areas. In 2004, the transportation sector contributed 23% of total energy emissions and land transportation accounted for 74% of transport contribution emissions[1]. These problems produce a variety of impacts, such as not being able to predict accurate travel time to a place due to dynamic traffic conditions, fuel wastage, decreased human productivity, causing riders or users to become stressful, dangerous conditions. The cause of this problem is not only due to the behavior of drivers or users of the course but the planning of the traffic rate becomes one of the factors that influence it[2]. Traffic information that is accurate and timely is needed by citizens, tourists, businessmen and government agencies. For that reason, researchers are constantly trying to find a solution to this problem.

Table 1: Comparison scale of transportation simulation

	Simulation scale		
Parameters	Macroscopic	Mesoscopic	Microscopic
Simulated unit	Traffic flow	Traffic flow	Individual behavior and route simulation
Fundamental theory	Physics, Mathematics	Physics, Mathematics	Cognitive study, Physics and artificial Intelligence
Data volume	Low	Medium	High
Computation needed	Low	Medium	Overall high
Stochastic behavior	Rare	Depends on model	Normally using stochastic application model Application model
Multi-agent and object interaction	Medium/low	Medium	Strong
Change reaction of traffic flow condition	Low	Medium	Strong

Traffic simulation is one of the ways to solve congestion problems by providing a device for testing and simulating traffic scenarios. Models in traffic simulations can be grouped into three categories based on the level of detail scale and the type of analysis to be performed. Three simulation scales are simulated in micro scale, simulated in meso scale and simulated in macro scale[3]. The micro-scale traffic simulation considers the details of each traffic flow and simulates each vehicle unit. The behavior of these vehicles can be modeled into two main models, the model following the vehicle or the car-following model (one example of this model is the Intelligent Driver Model (IDM)[4]) and the lane-changing model (one example this model is CAR[5]). Then the macro scale traffic simulation modeled the overall traffic flow dynamics and calculated the speed, traffic density and traffic[6]. Meanwhile, meso scale model is between micro scale and macro scale. The comparison between these three scales can be seen in Table 1.

For the simulation to run in accordance with actual traffic conditions, real-time data is needed in real-time that can be used in the simulator. Predicted traffic flows depend heavily on historical data and real-time data collected from various sensor sources (inductive loops, radar, camera, GPS, crowd sourcing, social media, etc.). Not always the data is available completely, therefore it needs an integrated hybrid model that can utilize incomplete data. A case in point is done in Bandung, which does not have enough censorship as in other major cities.

Literature review: There are several studies on the hybrid-micro-meso-macro traffic model. Here's a summary of what researchers have done since, 2000 to 2019.

The paper's study, entitled the interplay of multiple scales in traffic flow: coupling of microscopic, mesoscopic and macroscopic simulation, propose the idea of how to model-coupling environment by means of a micro-model simulated from a macro model of color coded.

This study show individual behavior is also affect macroscopic condition. Distribution of microscopic shows more impact to variable time to collision and time gaps. This case is also depending on macroscopic context (including volume and speed variable)[7].

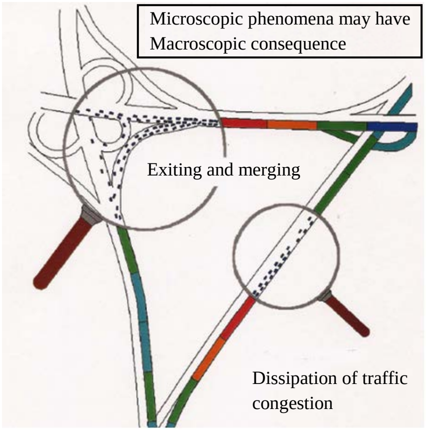

Fig. 1: Model coupling environment[7]

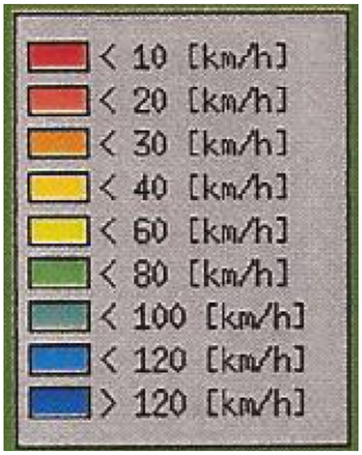

Fig. 2: Color classification on macro scale

George Lerner in his paper show microscopic Phenomena by using picture color tagging. Color represent traffic congestion in those area. Color tagging has been used by google and other platform to show congestion in such area (Fig. 1).

All the color and scale interaction represent by using model coupling. Each color has their own meaning. Where the red color means jam (heavy traffic) and blue color means smooth. Color detail can be described with this table (Fig. 2).

Fig. 3: Example of converting macro data to micro, then back to macros

The disadvantage of this method is, if the macro data distribution is not correct, then the generated micro model will error. The development step of this method is to record the entire historical data on microscopic, in order to be trained on macro data, thus, increasing accuracy (Fig. 3).

The study of the paper entitled modeling and application of urban dynamic region traffic model based on information fusion, propose the idea of how information from various traffic model scales can be combined (information fusion)[8].

The disadvantage of this method is need the data gradually, micro gives the data to meso, meso gives the result data to the macro. But all three are run separately (not simultaneously). The development step of this method is to do all three simultaneously (Fig. 4).

Study of the Paper entitled traffic simulation performance optimization through multi-resolution modeling of road segments, propose the idea of hybrid traffic simulation aimed at improving computing performance by up to 20%, while maintaining a 5% error deviation compared to pure microscopic[9].

Najia Bouha on his paper entitled A First Step Towards Dynamic Hybrid Traffic Modeling, propose the idea of combining microscopic and macroscopic models into a single framework. Where there is a switching algorithm that can change whether the simulator will run in micro scale or macro mode, depending on load of CPU used[10] (Fig. 5 and 6).

Safety and operation of large area rural/urban intermodal system publish a paper entitled integrating meso and micro-simulation models to evaluate traffic management strategies. They propose the idea of running two simulators with different scales (micro and macro) but with the same clock (sync) and there is also a data transaction between the two simulators. The intended result is the optimal route generated from the two simulators[11] (Fig. 7).

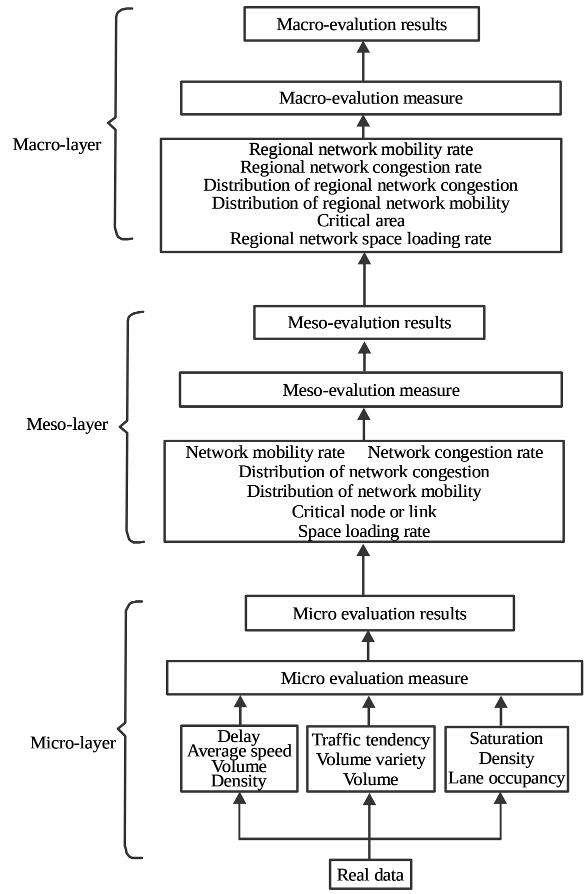

Fig. 4: Dynamic region traffic model

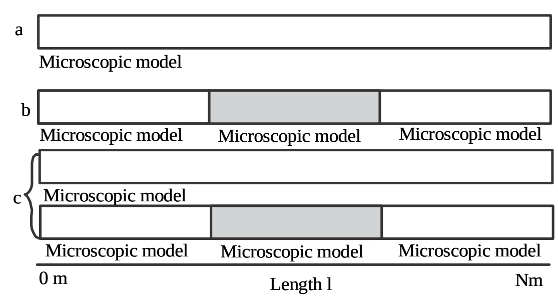

Fig. 5(a-c): (a) Microscopic mode, (b) Multi-resolution mode and (c) Dual-simulation mode

Data: Data is taken in Bandung city of Indonesia. Data taken using CCTV and counted by using software. This data has been validated manually with 5 people counted on the same frame of CCTV image. It is corrected with 15 error. Data is taken regularly every day from July 2017 to August 2019 (Fig. 8).

These data will have a unique data from Indonesia because there is no data about Pasteur bridge in this time range anywhere. We have 9 Sunday data from 3 month (Fig. 9 and 10).

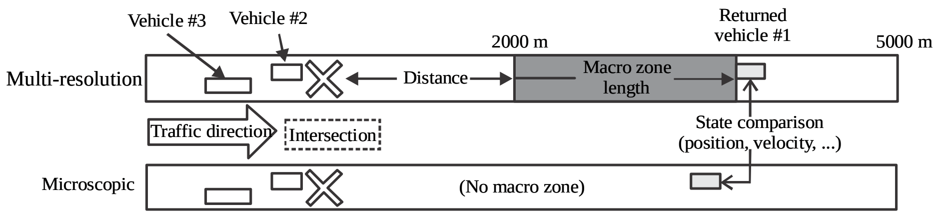

Fig. 6: Illustration of dual simulation mode setup

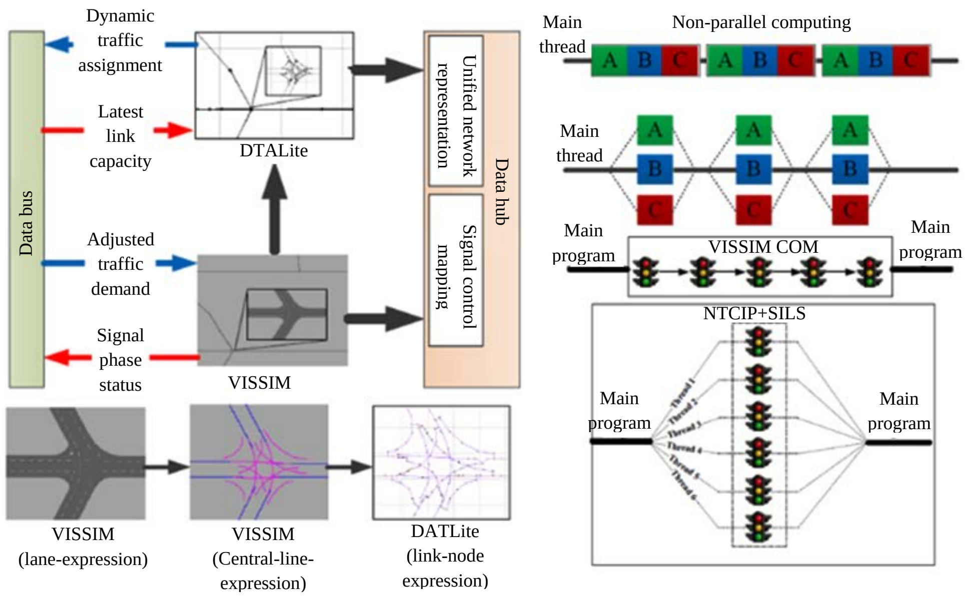

Fig. 7: System architecture of Metro Sim and network representation

Fig. 8: CCTV sample data taken regularly

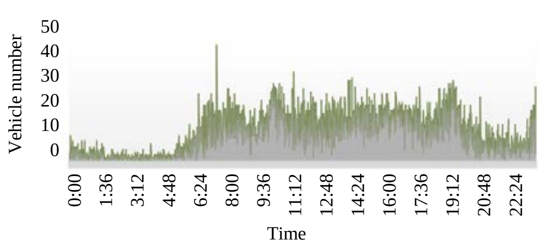

Fig. 9: Vehicle Density data on Sunday 9 July 2019

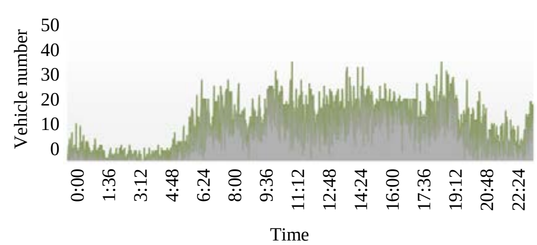

Fig. 10: Vehicle Density data on Sunday 9 July 2019

CAR FOLLOWING AND DENSITY MODELS

All the study paper showed, we can use hybrid simulator to have optimal route, computing performance and combining microscopic and macroscopic model. In this paper, there are 4 important point to show the model:

- Density per minute→average speed per minute
- Average speed per minute→acceleration and deceleration
- Accel. & Decel.→Micro-scale traffic model
- Micro-scale traffic model→Origin-destination matrix

Car following model: A model to represent car following each other:

$$\dot{x}_a = \frac{dx_a}{dt} = v_a$$

$$v_a = \frac{dv_a}{dt} = a\left(1-\left(\frac{v_a}{v_0}\right)^{\delta} - \left(\frac{s^*(v_a, \Delta v_a)}{s_a}\right)^2\right)$$

$$\text{with}\, s^*(v_a, \Delta v_a) = s_0 + v_a T + \frac{v_a \Delta v_a}{2\sqrt{ab}}$$

Density model: Purpose of this research. Density is defined as the number of vehicles per unit length of the roadway. Average speed is defined as average speed per 10 min. Density model can be shown in this equation:

$$k = \frac{1}{s}$$

$$K(L, t_1) = \frac{n}{L} = \frac{1}{\bar{s}(t_1)}$$

$$k(A) = \frac{n}{L} = \frac{n\,dt}{L\,dt} = \frac{tt}{|A|}$$

POPULATION GROWTH MODEL

Population is one of growth factor of vehicle in Bandung city. For that, need to be made a mathematical formula to be able to predict the population of the city of Bandung. This formula is useful to predict the number of vehicles in the city of Bandung (Fig. 11):

$$y_p(i) \cong \beta_{p0} + \beta_{p1}(i\text{-}k_p)^1 + \beta_{p2}(i\text{-}k_p)^2 + \beta_{p3}(i\text{-}k_p)^3 + \beta_{p4}(i\text{-}k_p)^4 \quad (1)$$

β_{p0} = 2125888
β_{p1} = 29977
β_{p2} = 3634,5
$ß_{p3}$ = -558,72
β_{p4} = 19,745
k_p = 2001
y_p = estimasi jumlah penduduk
i = tahun prediksi

Referring document Bandung city based on figures (2015, 2016, 2017, 2018) (Bandung central Bureau of Statistics), that the population in Bandung in 2015 amounted to 2,481,469, in 2016 amounted to 2,490,622, and in 2017 amounted to 2,552,276:

$$y_p(i) \cong \beta_{p0} + \beta_{p1}(i\text{-}k_p)^1 + \beta_{p2}(i\text{-}k_p)^2 + \beta_{p3}(i\text{-}k_p)^3 + \beta_{p4}(i\text{-}k_p)^4$$

$$y_p(2015) \cong 2.483.324$$

$$y_p(2016) \cong 2.507.216$$

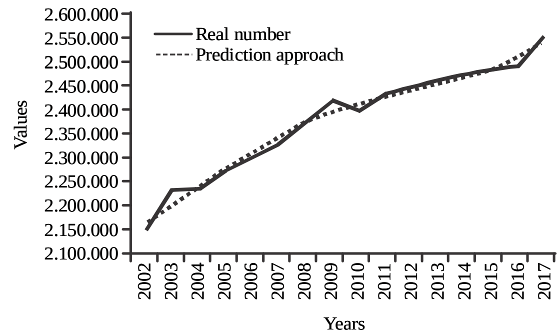

Fig. 11: Population growth in Bandung city. Blue line shows real number of Bandung city population. Orange dot line is prediction approach

$$y_p(2017) \cong 2.541.443$$

$$err_p(2015) = \left|\frac{2483324 - 2481469}{2481469}\right| = 0{,}0748\%$$

$$err_p(2016) = \left|\frac{2507216 - 2490622}{2490622}\right| = 0{,}6663\%$$

$$err_p(2017) = \left|\frac{2541443 - 2552276}{2552276}\right| = 0{,}4244\%$$

VEHICLE GROWTH MODEL

Referring document Bandung city based figures 2016 (Central Bureau of Statistics Bandung), Table 2, Page 102, total motor vehicles in 2015 amounted to 1.617.022.

Referring documents Bandung city based figures 2017 (Central Bureau of Statistics Bandung), Table 2, Page 194, total motor vehicles in 2016 amounted to 1,716,698.

Vehicle growth model in Bandung will comply to this equation:

$$y_k(i) \cong \beta_{k0} + \beta_{k1}(i - k_k)^1 + \beta_{k2}(i - k_k)^2 + \beta_{k3}(i - k_k)^3 + \beta_{k4}(i - k_k)^4 + \beta_{k5}(i - k_k)^5$$

β_{k0} = -34765
β_{k1} = 16509
β_{k2} = -1922,1
β_{k3} = 85,539
β_{k4} = -1,5845
β_{k5} = 0,0106
k_k = 1939
y_k = Vehicle Estimation Number
i = year prediction
y_p (2015)≅2.483.324 (99,93%)
y_p (2016)≅2.507.216(99,33%)

Table 2: Vehicle population in Bandung

Vehicle	Population (%)
Motorcycle	71.91
Personal car	22.55
Truck	4.64
Angkot	0.50
Bus	0.40
Total	100

CONCLUSION

Data from CCTV Cameras, updated per 1 min, produces an average density at a certain location and time. Data from Google traffic, updated per 10 min, produces an average speed at a certain location and time.

The density pattern of CCTV is consistent, except on national holidays or if there are special events/occasions. The data can also be used to calibrate (tuning) the traffic simulator.

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