Evaluating Road Networks Performance: Capacity Restraint Method

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Abstract. Traffic condition in Yogyakarta City faces growing volume each year. Meanwhile, the development of road is increasingly harder to expand due to limited availability of lands and funds. Therefore, evaluation of road networks is needed to avoid, reduce and eliminate traffic congestion in Yogyakarta. In this study, the authors aim to build road network model representing traffic condition in Yogyakarta. Capacity restraint method is used for traffic assignment with the assistance of ZIN software. ZIN capability to model complex road networks is also assessed.

1. Introduction
Based on Statistics Indonesia of Yogyakarta City, total vehicle ownership increases 7-12% each year until 2018 and no increase of road capacity or lengths occurred during the period. Meanwhile, the development of road is increasingly harder to expand due to limited availability of lands and funds. Demands increases while supply stagnant, results in traffic congestion which brings economic, psychological and environmental losses to road users.

Such conditions brings stakeholders to manage existing roads efficiently or deliver cost effective road infrastructures to satisfy the increasing traffic demands of urban areas. Objective evaluations of road network and impacts of various scenarios to existing conditions is needed to solve this. Mathematical model representing transportation system is proven useful for such conditions. Ortuzar and Willumsen (2011) define a model as a simplified representation of the system of interest which focuses on certain elements considered important from a particular point of view. This model attempt to replicate the system of interest and its behaviour by means of mathematical equations based on certain theoretical statements about it. It provide an objective common ground for every stakeholder to evaluate road network performance and evaluate various scenarios proposed with a level of objectivity.

In this study, road network model consisting of 228 roads, 856 links, and 18 nodes is build using ZIN software. Traffic flow is simulated using processed secondary observational data and primary data following classical four step travel demand model. This model flow is then validated against survey data from 81 major roads in Yogyakarta.

2. Methodology

2.1. Model Scope
The scope of the model decide the resolution of the system represented. An increase in scope results in more data needed and more variable used to model the system. The scope used in this research is macroscopic model. Daiheng Ni (2018) define a macroscopic traffic flow model as a model which
emphasize collective and average behavior of vehicles (flow, speed, density) and consider traffic flow as a homogenous compressible fluid. Macroscopic scope aim to capture the amount of fluid (i.e. number of vehicles) flowing into and out of roadway segments over time. The unit of vehicles is also adapted into light vehicles equivalent to make the unit uniforms with each other.

2.2. Four Step Travel Demand Model

The most widely used transportation planning methodology is the four step travel demand model. The first step is generating total movement from origin zone to destination zone. This step is called Trip Generation. The next step is distribution of traffic movement from origin zone to multiple destination zone within a certain pattern caused by interaction between land use, road network and traffic flow represented in a matrix called Origin-Destination Matrix (OD Matrix). This step is called Trip Distribution. The third step, Modal Split or Mode Choice is the likelihood of traffic user to choose certain mode from various alternative mode available. This step is ignored in this research and traffic user is assumed to choose private vehicle as transportation mode. The last step is assignment of OD Matrix to road network model using chosen assignment method named Trip Assignment.

2.3. Road Network Model

Transportation system represented in this road network model consists of the road networks and the behaviour of vehicles passing through the networks. Behaviour of vehicles includes relations between traffic flow variable (flow, speed and density), traffic zones, and routing problems.

Yosef Sheffi (1985) defines a mathematical representation of network as a set of nodes (or vertices or points) and a set of links (or arcs or edges) connecting these nodes. The road network in an urban area includes intersections and streets through which traffic moves. This representation assumes that all flow entering the intersection from a particular direction will experience the same travel time, regardless of where it is destined. It also cannot be used to represent turning restrictions. Various kinds of delay (traffic light, turning time, etc.) is represented by assigning delay function into the node of which the delay occurred. Muhammad Zudhy Irawan (2010) developed a volume delay function that represented the delay occurred from volume delay curve in Indonesia’s Highway Capacity Manual (1997) which gives more accurate representations of traffic condition in Indonesia.

Behaviour of vehicle observed in field using various sensor technologies and survey methodology shown dependence between the amount of vehicles passing through a road (traffic flows) and the speed or travel time needed to pass through a road. The exact relations between these 2 variables is unclear and debatable even until now. An attempt is made to bridge and equilibrate the exact relation of these variables with mathematical function. This is also known as traffic flow equilibrium model. In Indonesia, these relation is standardized by Indonesia’s Highway Capacity Manual (1997) such as that empirical data of Indonesia’s vehicle behaviour is represented by capacity parameter and free flow speed parameter using equations provided by the manual.

The transportation planning process for urban areas is typically based on a partition of the area into traffic zones. The size of each traffic zone can vary from a city block to a whole neighborhood or a town within the urban area. The number of traffic zones can vary from several dozens to several thousands. Each traffic zone is represented by a node known as centroid. These traffic zones or centroid represent the total movement of vehicle in the given urban areas. It is also known as generation and attractions or origin and destinations. The matrix describing the number movement between traffic zones is called Origin and Destinations Matrix (OD Matrix).

As traffic flow equilibrium is mentioned, the problem of finding the equilibrium flow pattern over a given urban transportation network is also known as traffic assignment. There is various method of traffic assignment with different assumptions taken with each theory. The method used in this research is capacity restraint method. Capacity restraint method is a variation of all or nothing method. In the all-or-nothing method, each O-D pair is examined in turn and traffic flow is assigned to every link with the minimum travel time path connecting origin to destination. All other paths connecting this O-D pair are not assigned any flow. This results in all traffic flow overflow the road with least travel times and ignore the dependence between traffic flow and travel times. In an attempt to capture the equilibrium nature of the traffic assignment problem, transportation planners have devised an iterative
scheme known as capacity restraint. This method involves a repetitive all-or-nothing assignment in which travel times resulting from the previous assignment are used in the current iteration.

2.4. Capacity Restraint Method

The algorithm can be summarized as follows:

Step 0: Initialization. Perform all or nothing assignment based on \( t^0_a = t_a(0) \) or \( a \). Obtain a set of link flows \( \{x^0_a\} \). Set iteration counter \( n=1 \).

Step 1: Update. Set \( t^n_a = t_a(x^{n-1}_a) \) or \( a \).

Step 2: Smoothing. \( t^n_a = 0.75t^{n-1}_a + 0.25t^n_a \), or \( a \).

Step 3: Network loading. Assign all trips to the network using all-or-nothing based on travel times \( \{t^n_a\} \). This yields a set of link flows \( \{x^n_a\} \).

Step 4: Stopping rule. If \( n = N \), go to step 5. Otherwise, set \( n = n + 1 \) and go to step 1.

Step 5: Averaging. Set \( x^*_a = \sum_{t=0}^3 x^{n-1}_a \) or \( a \) and stop. (\( \{x^*_a\} \) are the link flows at equilibrium.)

2.5. Linear Regression Analysis

Validation method used in this research is linear regression analysis. Linear regression analysis is a statistical method used to discover relationship between independent variable and dependent variable stated by equation \( y = mx + c \). Due to unique condition of which relationship wanted between validator data and model data is the exact same value, the equation became \( y = x \). With this known condition, method of least squares is used in regression analysis represented by using intercept function to point \((0,0)\) in excel.

the analysis of the reliability of model data (independent variable or \( y \)) to explain validator data (dependent data or \( x \)) is found by using determination coefficient \( (R^2) \) in linear regression analysis within the number of data used \( (n) \). The equation used to find determination coefficient is expressed in the equation below.

\[
R^2 = \frac{(n \sum xy - \sum x \sum y)^2}{(n \sum x^2 - (\sum x)^2) \times (n \sum y^2 - (\sum y)^2)}
\]  

(1)

3. Location

This research is conducted in Yogyakarta City. Yogyakarta is partitioned into 18 traffic zones based on 14 sub-district administrative level in Yogyakarta City as internal areas and 4 other traffic zones representing external traffic flow. Roads network consist of national, provincial, and several city class roads deemed to have impact on traffic flow in Yogyakarta City. Inner zone movements is not considered. 228 roads is considered with 856 links representing the roads.

Figure 1. Yogyakarta Road Network
4. Research Results
Traffic flow is simulated using ZIN software with modelled road network using road network and OD matrix secondary data from Transportation System Study on Local Transportation Level of Yogyakarta City in 2015 and 4.5 minutes of delay assumption taken on each signalized intersection. Validator data is sourced from secondary data of field survey conducted by transportation agency of Yogyakarta City.

Figure 2a. Trip generation and attraction in Yogyakarta City. Figure 2b. Trip desire line in Yogyakarta City. Figure 2c. Volume capacity ratio in Yogyakarta City Figure 2d. Traffic velocity in Yogyakarta city
Figure 3. Validator volume against model volume.
Figure 4. Linear Regression Analysis

Result shows that road network modelled by ZIN software with capacity restraint method validated using linear regression method with determination coefficient ($R^2$) value of 0.6839 and with equation of $y = 0.839$ against 93 validator data. Results shown 15% of the data has relative error under 10%, 37% has relative error above 10% and below 50%, and 48% has relative error above 50%. The modelled traffic condition tend to be short term due to accuracy of data used and limitations and assumptions taken by the modelling theory used by the software.

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