Exploring the effectiveness of demand management policy in reducing traffic congestion and environmental pollution: Car-free day and odd-even plate measures for Bandung city in Indonesia

Muhammad Farda[1,2] & Chandra Balijepalli[3,4,5]

ABSTRACT

Traffic congestion has been a major problem in big cities around the world, not to mention several large cities in Indonesia. Bandung is the second largest metropolitan area after Jakarta in Indonesia which suffers from extreme levels of congestion. With a high number of motorcycles and large private car population, congestion in this city is ever growing worsening the environment. While the local authorities struggle to find resources to fund capital intensive capacity expansion projects, this research explores the use of cost effective demand management policy measures to reduce the congestion and pollution. This study aims at assessing two relatively under-researched demand management policy measures that restrict vehicle flows viz., *car-free day* and *odd-even plate* schemes to investigate the effect on traffic congestion and the environment. SATURN traffic network modelling software has been used to predict the route choices of vehicles. Bandung city road network and origin destination matrix have been adapted to simulate the two measures during the peak hour. As well as providing the necessary inputs to a pollutant emission estimation model, traffic network modelling output forms the basis for assessing the congestion levels. Results show that both car-free day and odd-even plate measures have unintended consequences that undermine their effectiveness which if addressed could make them highly beneficial solutions. Car-free day scheme reduces the traffic flow levels in the vicinity of scheme but diverts the vehicle flow elsewhere to other routes which may adversely affect the congestion/pollution. Odd-even plate scheme is very effective at the beginning of its implementation but the performance gradually diminishes as drivers start to adapt by buying a second vehicle or even using fake number plates.

Keywords: traffic congestion, demand management policy, car-free day, odd-even plate, pollutant emissions

1. INTRODUCTION

Big cities around the developing world are now facing traffic congestion problem which is usually due to an increasing population coupled with the need for reaching activities located in different parts of the city. In South East Asia around 42 % of the population from a total of 245 Million lives in urban areas and this proportion is expected to reach nearly 50% by 2025 (Institute for Southeast Asian Studies, 2010). South East Asia's biggest country, Indonesia, particularly metropolitan areas of Jakarta and Bandung is no exception to this problem. In year 2000, Jakarta Metropolitan Area (JMA) and Bandung Metropolitan Area (BMA) together held 28% of Indonesia's urban population (Firman 2009). Jakarta and Bandung are really attractive destinations to migrants because of a number of job and education opportunities available. As the demand for transport is a derived quantity from the activity levels, increase in population also means an increase in the need for movement. Inadequate transport facilities, ill-maintained infrastructure and weak regulatory measures will lead to big cities' common problem, namely traffic congestion. The trend in increasing population followed by increasing demand for movement has resulted in severe congestion in both Jakarta and Bandung Metropolitan Areas along with significant impact on environment due to vehicular emissions. Exposure to high level of emissions poses a considerable risk to human health, including those who

[1] Bandung Institute of Technology, Bandung 40132, Indonesia
[2] E-mail: muhammadfarda2@gmail.com
[3] Institute for Transport Studies, University of Leeds, Leeds LS2 9JT England
[4] Corresponding author
[5] E-mail; n.c.balijepalli@leeds.ac.uk

Please cite this article as: Farda, M. & Balijepalli, C., Case Studies on Transport Policy (2018), https://doi.org/10.1016/j.cstp.2018.07.008

are the most vulnerable in the society. A study by Carrier et al. (2014) shows that, in Montreal, several elementary schools particularly the deprived ones are located in polluted areas due to vehicle emissions.

Cities in Indonesia have a special traffic characteristic too, which is a very high number of motorcycles dominating the proportion of all travel modes. According to Bandung Central Statistics Agency (2015), modal share of motorcycles reached approximately 72.2% in 2013. A study by Dharmowijoyo et al (2015) also shows that approximately 75% of respondents in Bandung have access to a motorcycle. If the increasing urbanisation coupled with increasing private vehicle ownership continues, the city is likely to experience a gridlock situation in the near future. Moreover as a result of high traffic volumes, the pollutant emissions arising from road traffic are also reaching levels well over the acceptable limits. In order to alleviate the traffic congestion, local authorities commonly rely on capacity expansion policy which may be capital intensive. Many local authorities struggle to fund the capital intensive capacity expansion projects, however, they are known to be less efficient as they generate more traffic (SACTRA 1994). As an alternative, cost effective demand management measures were tried which aim at managing the demand to reduce congestion/pollution by altering the route, destination, departure time and mode of travel. Leo et al. (2016) shows demand management measures can improve traffic condition in many aspects, including less congestion, less pollution, less energy consumption and improvement to well-being. Within the remit of demand management, road user charging and parking management schemes have been well researched. In this research, we aim to explore the use of two relatively under reported measures viz., car-free day scheme and odd-even plate scheme for Bandung city in Indonesia.

Car-free day and *odd-even plate measures* caught the attention of planners recently more than ever (Decy et al 2015, Cai & Xie 2011, Cantillo & Ortuzar 2014), partially due to the pressure on local authorities to deal with the traffic congestion but also due to the need of taking an action to reduce the pollutant emissions from road traffic. Between the two measures car-free day's main intent is to reduce the pollution but it is important to assess the impact of its unintended consequence due to diversion of traffic. On the other hand, odd-even plate measure is intended at reducing traffic congestion in some places (e.g. Medellin) while some other cities (e.g. Delhi) seek to reduce the pollution levels.

Car free day scheme is a simple and cost effective demand management measure which restrains the use of unsustainable modes of transport by banning for example motorised modes of transport on a particular day/time period on a given road. During the car-free day period, interaction between people and communities is encouraged by allowing only pedestrians and cyclists to use the road. In some cases, car-free day also creates an opportunity for people to share their message, deliver musical performances while also increasing the sales for shops around. By banning unsustainable modes of transport on a road, improvements are expected in terms of local air quality, social interaction and people's health and wellbeing. In contrast, odd-even plate scheme bans vehicles with a particular plate number ending from entering a particular road section/or an area on certain days (usually odd or even plated but some variants may involve banning plates ending with 1-2 on Mon, 3-4 on Tue and so on as in Manila, for example). Odd-even plate scheme may be implemented in the entire city (as in Delhi) or even in some parts of the city (e.g. Jakarta) though may not be ideal for passing traffic.

Both car-free day and odd even schemes have been implemented though on a limited scale in cities around the world including China, India, Indonesia, Philippines and Central/Latin America, however, a comprehensive analysis of network-wide effects of these policy measures is yet unavailable. Analysis of impact of the two measures over an entire network attains significance due to the diversion effects that are likely to be experienced elsewhere on the network. Car free day measure is likely to have a far reaching effect as many other alternative roads are likely to be congested. Similarly odd-even plate measure is expected to reduce the traffic, but the impact of the measure is likely to fade out as the drivers adapt to the measure over time. Thus it is important to analyse the impact of the measure not just in the year when it is initiated but over a period of time into the future too.

The main aim of this paper is thus to explore the use of traffic demand management policy in easing the traffic congestion and the specific objective is to investigate the performance of the two measures viz., car-free day and odd-even plate schemes for the case of Bandung city. Impact of both the measures is modelled over a 6-year period from 2015 to 2021 which also considers exogenous traffic growth. Resulting network performance and vehicular emissions are used to assess the effectiveness of the two schemes. This paper is divided into six sections including the introduction. Section 2 reviews the literature and section 3 introduces the study area and the data needed for policy analysis. Section 4 describes the methodology and section 5 discusses the numerical results from the case study. Section 6 concludes the work and identifies policy implications.

2. LITERATURE REVIEW

This section reviews the past studies that reported implementing car free day and odd-even plate measures. There are three studies of car-free day scheme implementation including one in Hungary and two others from Indonesia were reviewed as part of our study. Similarly three cases of odd-even plate implementation in Beijing, Medellin and Delhi were reviewed. A common thread through all the cases is reducing the pollution levels due to road traffic which seems to be the main aim of the two demand management schemes. From the review we will be looking for lessons to be taken ahead for the case of Bandung city.

2.1 Car free day scheme

2.1.1 The case of Veszprem, Hungary

Georgina et al. (2014) evaluated the spread of air pollution as a result of the car-free day implementation in Veszprem, Hungary. The study measured air pollution at a location close to the car-free day area during the European Mobility Week on 20th September, when the car-free day was implemented. The devices used to measure the air pollution were a non-dispersive infrared analyser, fluorescence analyser, etc. The measurement was then compared to air pollution on 27th September, also known as “control day”.

According to the results, NO_2 and SO_2 recorded a higher concentration during the car free day while particulate matter (PM) was lower compared to the control day. Georgina et al. (2014) noted that there was unusually large congestion close to where the monitoring device was placed. The congestion was due to parents dropping their children in the morning and picking them up in the afternoon from a school located close to the car-free day area. It was also noted that as a result of car-free day implementation, road routes available for drivers had reduced which caused congestion in certain locations as a result of traffic diversion, especially during peak hours. Regarding particulates, the concentration was higher during the car-free day because there was an activity for elementary and high school students which involved a run around the car-free day location as a celebration. This resulted in an increase in concentration of dust around the area (Georgina et al., 2014).

2.1.2 Car free day in Denpasar, Bali

Car-free day scheme has been implemented in some Indonesian cities although during weekends. Decy et al (2015) analysed the effectiveness of car-free day scheme regularly implemented from 7am to 10am over weekends on Puputan Niti Mandala Main Road. The study compared the pollution concentration observed on Sunday, 8th May 2011 with a normal workday on Monday, 9th May 2011. The amount of pollution during regular workday was notably higher compared to that during car-free day period. For instance, the amount of SO_2 on car-free day and workday was 69.74 ($\mu g/m^3$) and 74.54 ($\mu g/m^3$) respectively. In the case of NO_2, the amount for car-free day and workday was 54.36 ($\mu g/m^3$) and 74.118 ($\mu g/m^3$) respectively. The method also compared vehicle counts on roads around, when/where car free day is/isn’t implemented. The study suggested that the impact on other locations where traffic is diverted should also be calculated. This suggestion is a reasonable one as it is obvious that the pollution during the workday will be significantly higher as during the car-free day, no car is allowed to use the car-free day location and the pollution monitoring survey was only conducted on the car-free day area. Thus, lower pollution levels during the car-free day in the respective location need not necessarily mean that the level of overall pollution has reduced. The traffic may be diverted to somewhere else, and thus polluting the other locations.

2.1.3 Car free day in Surabaya, Indonesia

Kanaf and Razif (2010) analysed the impact of the car free day measure in terms of traffic flows in Surabaya city, Indonesia. The car-free day in Surabaya city runs from 6am to 9am on Sundays. It was noted that there were both positive and negative changes in traffic flows on road sections surrounding Kertajaya Road where the car free day was implemented. In particular, roads surrounding Kertajaya Road have witnessed an increase traffic flows while that on Kertajaya Road itself fell. This shows that car-free day policy need not necessarily restrain the vehicle demand, but potentially tends to divert the traffic elsewhere. The pollution levels too followed the flow patterns with higher emissions recorded on roads with an increase in flows and vice versa.

2.2 Odd-even plate scheme

The odd-even plate number policy is currently being considered by several governments around the world to solve traffic/pollution problems. Countries like China and India have undertaken trials to see the impact of the policy while Indonesia has just started a trial of this measure. Beijing (China), some Latin American cities e.g. Medellin (Columbia), Mexico city (Mexico) and more recently Delhi (India) have all trialled the odd-even plate method in the recent past.

2.2.1 Odd-even plate scheme in Beijing, China

Beijing city implemented the measure during Beijing Olympics for a period of two months around the international sporting event (20th July – 20th September 2008). Cai and Xie (2011) shows that the amount of average daily traffic decreased significantly when odd-even scheme was implemented but it was back to its initial state after the scheme was removed when the sporting event has concluded. In case of Beijing Second Ring Road, the average daily traffic declined by 20% from around 10 Million/day to 8 Million /day after the policy was implemented. After it was removed, the number rose up again to around 10 Million/day. Consequently, emission amount also followed the same trend. However, a clearer understanding of the network-wide impact is required if we were to look at this policy for a wider implementation.

2.2.2 Odd-even plate schemes in Medellin (Columbia) and Mexico City (Mexico)

Cantillo and Ortuzar (2014) argued that the odd-even plate scheme has the optimum impact during its early phase of implementation. People will then try to adapt to this policy by using fake plates or even by buying a second car with different kind of plate number. In Medellin City (Columbia), the number of registered cars increased sharply after this policy was implemented in year 2005 and the vehicle numbers almost doubled by 2010. In Mexico City, after the policy was implemented for the first time in 1989, modal share for car decreased significantly but then rose again. Cantillo and Ortuzar (2014) also explained that as households have now had more vehicles, they can use all of their vehicles when the policy is not implemented e.g. during weekend resulting in worsening emission amount during the weekend.

Table 1 Modal share in Mexico City

Mode	1983	1986	1989	1992	1995
Bus/Minibus	48.2	47.8	53.6	59.7	55
Taxi	5	5	5.9	8.2	8.5
Car	23	24.9	16.4	17.8	22.2
Light Rail – Metro	1.7	3.2	3.1	1.1	1.2
Metro	22.1	19.1	21	13.2	13.1

Source: Comentravi, 1999, cited in Cantillo and Ortuzar, 2014

2.2.3 Odd-even plate scheme in Delhi, India

Government of Delhi has implemented odd-even plate method of banning vehicles on their road network for a limited period of 15-days in January 2016 with the aim of curbing the pollution levels.

It is known that particulate pollution in Delhi during 2008/11 period averaged between 123±87 mg/m^3 for PM2.5 and 208±137 mg/m^3 for PM10, both exceeding the national annual ambient standards of 40 mg/m^3 and 60 mg/m^3, respectively (Guttikonda & Goel 2013). During the implementation period, PM2.5 which accounts for nearly 16000 pre-mature deaths and six million asthma attacks per annum in Delhi fell by 10-13% and at some locations by even 18% during peak times (Subramanian, 2016a, b). Delhi city then underwent a second trial of the ban in April 2016, however the road traffic levels were more than those observed in January trial period earlier. The local authorities found the scheme extremely difficult to enforce the ban and as noted by them there were half a million more vehicles in April compared to January trial period. This clearly shows that the scheme is extremely hard to implement over a long period of time as the drivers are likely to find ways to avoid the scheme (e.g. by buying a second vehicle) and as such can be looked at as a scheme for short periods such as special events.

2.3 Comments on car free day and odd-even plate implementation

The above studies yield a very important lesson which has a significant bearing to this paper. Firstly, in terms of car-free day impact assessment the analysis should be made based on do-nothing and do-something scenarios which means that the measure is assessed for the same critical time period of the day e.g. *peak hour*. In addition, as the car-free day measure has a tendency to divert vehicles to other routes, the analysis should encompass a *wider area of the city* so that the diversion impact of the measure on other routes can be captured effectively. Secondly, in respect of odd-even plate scheme, the effect of the measure is quite strong during the immediate phase of implementation but seems to decline as the time passes by as a result of the driver adaptation. To capture this phenomenon, analysis should encompass *longer horizon* and take into consideration peoples' adaptation behaviour, particularly in terms of declining number of vehicles being affected by the measure over time. For this purpose, we model the traffic flow in Bandung city over a period of six years using network modelling method as set out in the ensuing sections.

3. STUDY AREA AND DATA COLLECTION

In this paper, car-free day and odd even plate number plate schemes will be tested for Bandung city in Indonesia. The city is spread over an area of 167.31 km^2 which is inhabited by 2.47 Million people with about 15,713 persons/km^2 population density in year 2014 (Bandung Central Statistics Agency, 2015). Bandung city is also a part of and located at the centre of a wider area called Bandung Metropolitan Area with a population around 8.3 Million (Syabri, 2013). For the purpose of this study we focus on Bandung city area (Figure 1).

Please cite this article as: Farda, M. & Balijepalli, C., Case Studies on Transport Policy (2018), https://doi.org/10.1016/j.cstp.2018.07.008

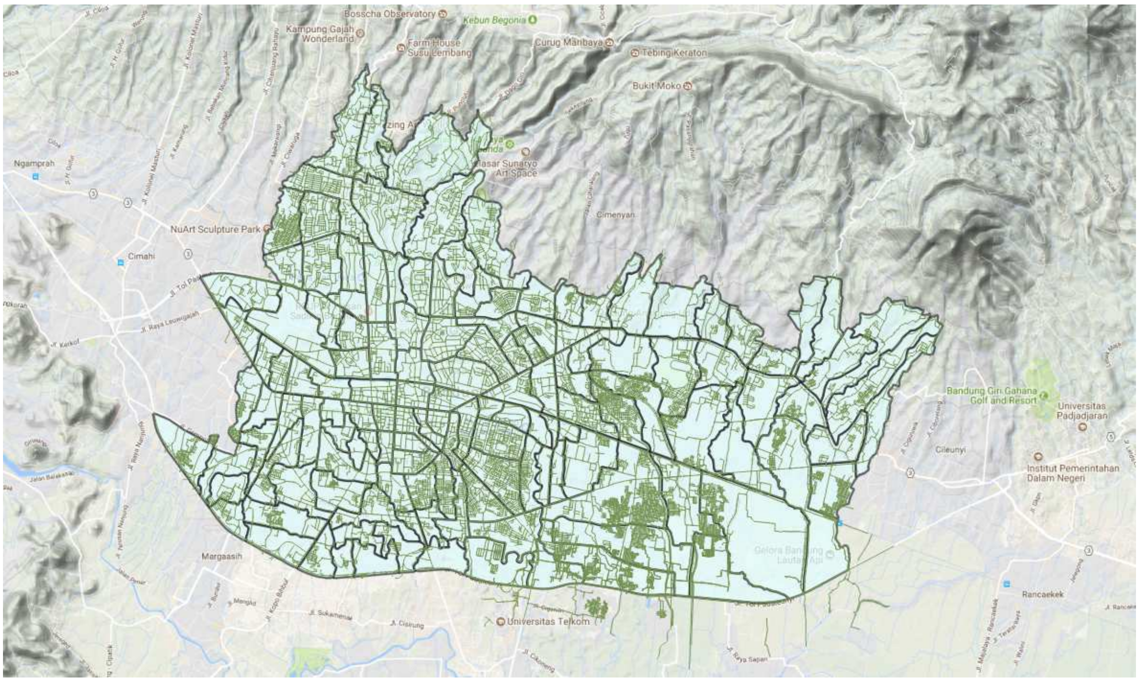

Figure 1 Bandung city

Appropriate location for car-free day measure is determined based on the criteria described later in this paper and the location for odd-even plate scheme is the whole of Bandung city's road network. Both the measures will be tested for a peak hour on typical a week day. The scope of the work means we need to simulate the traffic flow on the entire network of Bandung in order to assess the impact both at the location where the scheme is implemented and also the distributed impacts over wider parts of the network. Thus in addition to network configuration, we will also require the knowledge of travel patterns in Bandung. For the purpose of the research, we have obtained coded road network of Bandung city and the Origin-Destination (O-D) matrix representing the peak hour travel patterns (in terms of passenger car units per hour) from the Transportation Laboratory of Institute of Technology Bandung (ITB). The SATURN network supplied divided the city into 177 traffic zones based on sub-districts consisted of link based information (commonly known as 'buffer' network) which does not have any detail of junctions. Link based information received includes length of each link, capacity, free flow speed and speed at capacity and a relationship between flow and delay representing how the travel time increases with an increase in flow. However, for the purpose of the research we needed a more detailed network set up in terms of the details of the junctions which will enable modelling the turning flows and hence accurate estimation of the flows/delays. Hence we have resorted to converting parts of the 'buffer' network into a detailed 'simulation' network by including details of junctions such as type of junction – traffic light, roundabout, priority etc., number of approaching lanes (and their allocation to turns), traffic light splits if the junction is signalised for all the junctions located within the city centre of Bandung. Traffic counts have also been collected which are used for validating the model.

4. METHODOLOGY

The main method used to analyse car-free day and odd even plate number policy involves using standard traffic assignment modelling methodology. The methodology involves modelling of peak hour traffic as is customary in highway assignment models for urban areas (DfT 2014) which assigns drivers (trips) in peak hour to alternative routes between O-D pairs until no driver on the network can find a cheaper route than their currently allocated route. The network is then said to have reached an equilibrium state as defined by Wardrop (1952). In order to solve for the equilibrium, this research used assignment modelling module available within SATURN software (Van Vliet and Hall, 2004) although any other modelling suite could be equally used provided the initial datasets available are compatible with the modelling software chosen. Bandung city SATURN network is shown in Figure 2.

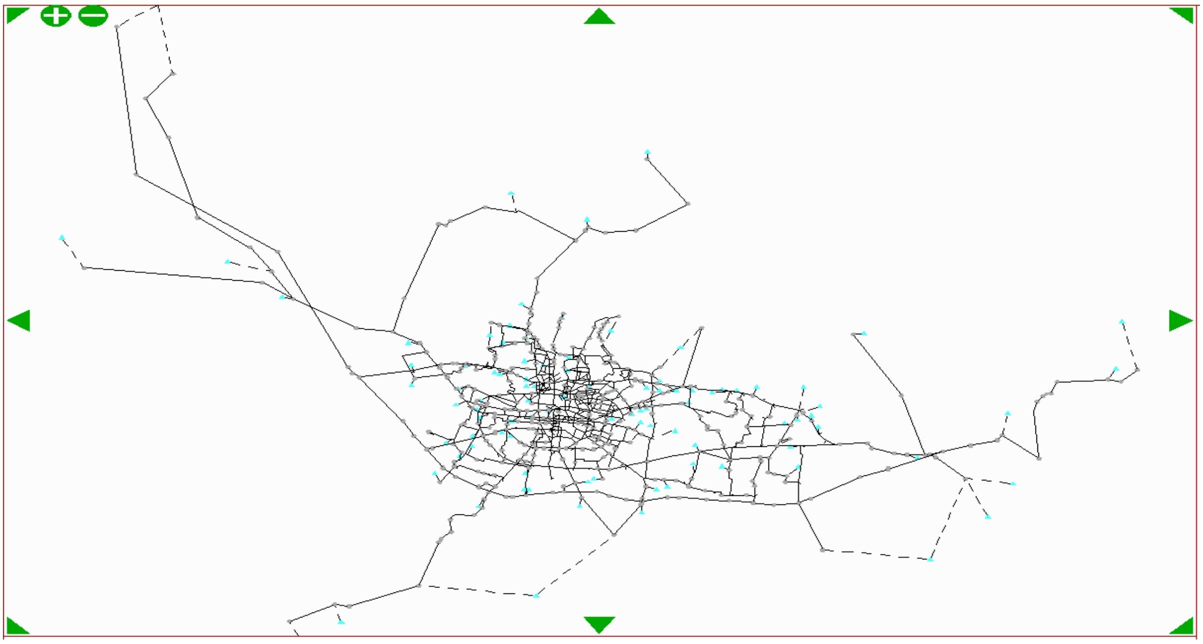

Figure 2 Bandung city SATURN network

(The modelled road network has about 1300 links connecting 177 traffic zones)

In order to represent the two policy measures viz., car free day and odd-even plate schemes, significant modifications need to be made to the SATURN network and/or O-D matrix.

Firstly, to model the car-free day scheme during peak hour, road network links where car free day is implemented need to be banned for cars and two-wheelers (although it is known as a '*car*' free *'day'* scheme) by adding a large *penalty* to discourage banned vehicles from entering the restricted stretch of road. The penalty is usually applied in the form of time added to the link travel time which increases the generalised cost of travel time of all routes using the chosen link to be above the cost of travelling through alternative routes. A large value of penalty can be added to any link by using the network editing facilities in SATURN or directly editing the network data file. Thus the network editing is a key step in modelling the car free day scheme. Another important step is to identify an appropriate location for car free day scheme. The location of car free day scheme is decided by taking into account the main objective which is to reduce the congestion and pollution in the area by encouraging people to use alternative routes and environmentally friendly transport modes e.g. walking and cycling.

Thus the main criteria for choosing a location to implement car free day scheme are as listed below:

- a location where it is convenient for people to walk or use a bicycle e.g. road with lots of greenery around;
- a road which has high volume of traffic relative to its capacity together with alternatives to use if banned from entering; and
- a location likely to yield optimal impact in terms of emission reductions which is dependent on the number of vehicles passing through the road.

Secondly, the odd-even plate method has been applied all over the network during the peak hour. Unlike the car free day scheme which required editing the network link properties, odd-even plate method requires adopting peak hour O-D matrix to represent appropriate demand levels in each year of implementation. Clearly implementing the policy will reduce the number of vehicles travelling on the road while its unintended consequences in terms of driver adaptation over time will affect the numbers by bringing them back undermining the impact of this policy. Steps involved in adopting the O-D matrix have been described further in Section 4.2 later.

4.1 Car-free day scheme

In Bandung we have chosen Asia-Afrika Road 1.5 km long one-way street (Figure 3) which satisfies the main criteria as set out earlier viz., this road is walking/cycling friendly due to a lot of green space around. It is also centrally located in the city thus making the attractions around e.g. historical sites easily accessible. Finally Asia-Afrika Road has a very high volume of traffic in normal circumstances and from preliminary model runs we noted that the road has a flow level of 3400-4200 passenger car unit equivalent flow per hour – pcu/hr (Figure 4) which is considered to be very high among other similar roads.

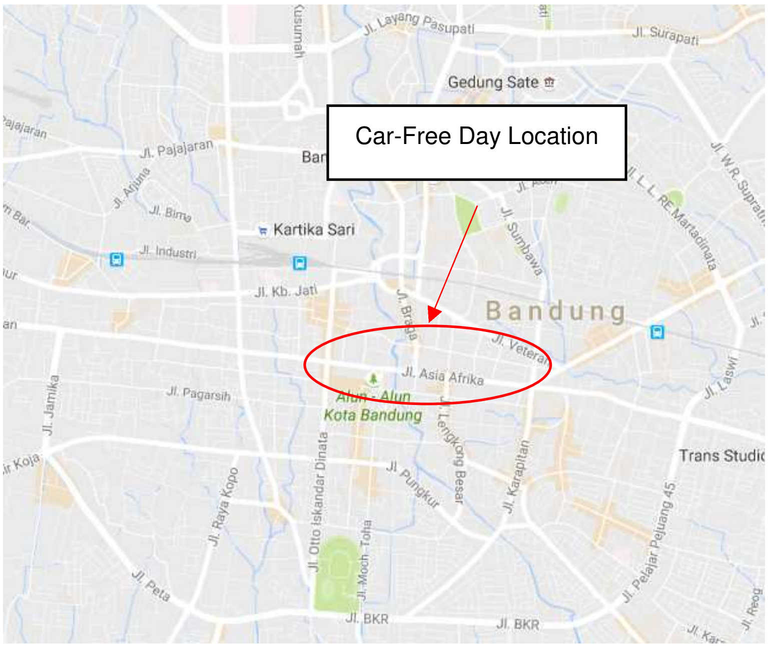

Figure 3 Car-free day location

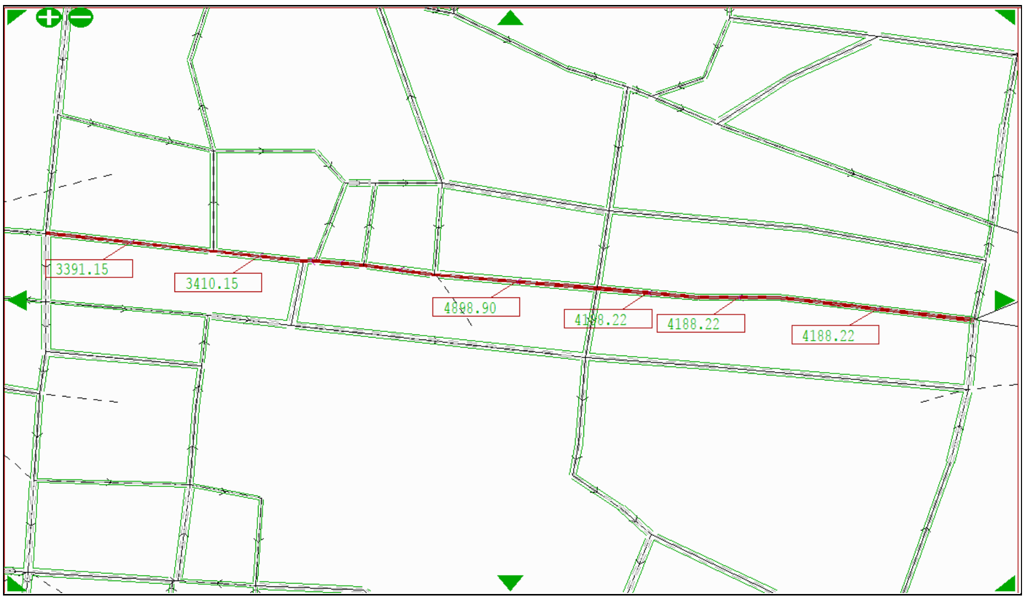

Figure 4 Initial demand flow (in passenger car units, pcu/hr) on Asia-Afrika Road section

The selected road section (consisting of several links in the coded model) is then restricted for all vehicles in the peak hour SATURN model of Bandung city by applying a very high time penalty to represent car-free day scheme. No vehicles will be able to drive through this road section during the peak hour when very high time penalty is applied mimicking the car free day scheme for the rush hour. Learning from the experience of previous studies we aim to take into account the *traffic diversion* effect arising from car-free day scheme over wider parts of the network. Thus the study area for this policy is divided into two parts. The first part includes the area where car-free day is implemented together with a few surrounding roads, which hereafter is referred as *cordoned area* (Figure 5) and the other part is the *area outside cordoned area* which is simply equal to the subtraction of cordoned area from the complete network. By looking at the network in two areas, the impact of car free day scheme in terms of traffic congestion, speed of travel, traffic emissions can be analysed with a spatial focus. Traffic diversion effect is accounted for by analysing the link flows, total travel time (pcu-hr) and total travel distance (pcu-km) and the emissions are computed with the help of an estimation model as described in Section 4.3.

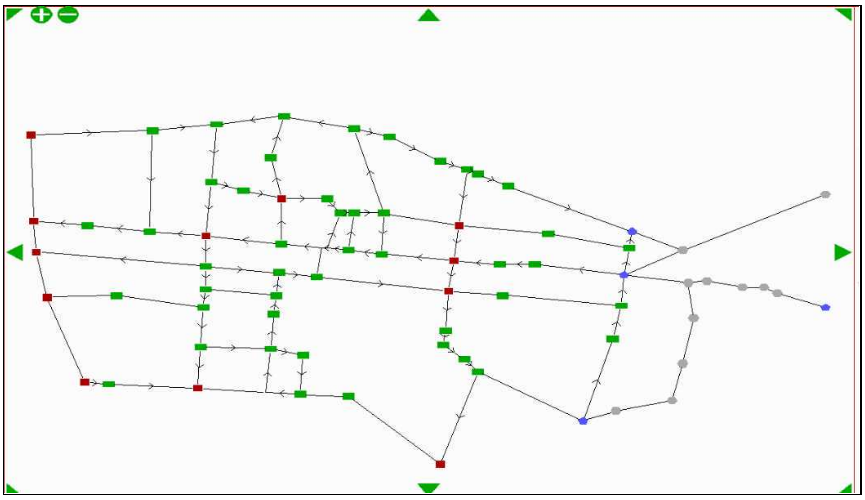

Figure 5 Cordoned area of Bandung city

(In the figure, squares indicate junctions with traffic lights and rectangles indicate priority junctions, pentagons indicate external nodes connecting simulation/buffer networks and circles indicate dummy nodes included to give a shape to the network links)

4.2 Odd-even plate scheme

The odd-even plate scheme needs adjusting the demand and is modelled by using matrix slicing techniques. We consider two methods – (i) *simple matrix slicing* and (ii) *random matrix slicing* methods. As we do not know a-priori the number plate data in each modelled traffic zone, we assume intuitively that half the vehicles in each zone are even plated and the other half odd plated vehicles. Hence this method is referred as *simple matrix slicing* or 50:50 slicing which simply divides the matrix cell values of the O-D matrix into two halves. But this may be considered too naive an assumption and thus we developed a variant called *random matrix slicing* method in which we assume a random proportion of vehicles in each zone to have an even plate and the remaining odd-plated. We have used Monte Carlo simulation technique for this purpose which involves generating uniformly distributed a random number per traffic zone. The random numbers generated have been applied to each of the cells in the OD matrix (177 origins × 177 destinations = 31,329 O-D pairs in all) to slice up the matrix. (It is noted that the random number generated is uniformly distributed between zero and one and will yield an average of 0.5 if all the random numbers generated are averaged). The main idea is that if odd-even plate number policy is implemented, 50% of total vehicles should be out of the road while the other 50% use the network on any given day. The assumption will thus mean that if each resident has access to a single vehicle, then the proportion of vehicles with odd and even plate number ending will be almost equal to 50:50.

Interestingly, according to the past experience, odd-even plate method did not result in a 50% reduction of vehicles on the road for various reasons. For example, in Medellin the number of vehicles has almost doubled in 6 years after the odd-even plate policy was implemented as many bought a second vehicle (Cantillo and Ortuzar, 2014). Some other drivers were able to apply for an exemption from this policy e.g. VIP's, disabled drivers. Emergency vehicles such as ambulance, police, fire tenders too needed to be exempt from the policy. In addition, there was always a risk of certain drivers adapting to the scheme by using fake number plates. Thus in order to model the driver behaviour together with the legitimate exemptions allowed, we have profiled the adaptations as a simple linearly increasing function as shown in Figure 6.

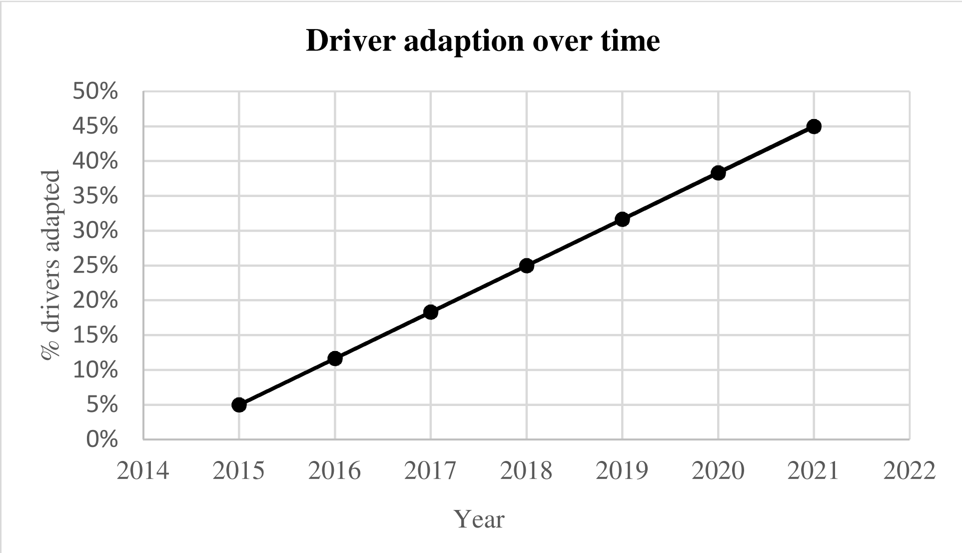

Figure 6 Driver adaptation profile

The driver adaptation proportion steadily increases to represent their behaviour which means familiarity with the policy will make them find ways to avoid it somehow e.g. by owning a second vehicle or by using fake plates or by applying for an exemption if possible. The number of cars on Bandung road network on any day will then be equal to the sum of the allowed vehicles to travel on the day plus the number due to driver adaptation. The number of vehicles travelling on the road for each O-D pair 'ij' is then calculated as follows:

$$T_{ij}^2 = T_{ij}^1 * (SF + A_f) \quad (1)$$

where,

T_{ij}^2 = Number of trips from origin 'i' to destination 'j' after exemption of cars

T_{ij}^1 = Number of trips from origin 'i' to destination 'j' before exemption of cars

$$SF = \begin{cases} 0.5 & \text{if simple matrix slicing} \\ [0,1] & \text{if random matrix slicing} \end{cases}$$

A_f = Adaptation factor

Adaptation factor A_f is read out from the graph shown in Figure 6.

4.3 Traffic congestion indicators, emission calculations

The following outputs from traffic assignment model have been used to indicate the network performance in terms of congestion on the network:

- Link flows (pcu/hr)
- Links with volume to capacity (V/C) ratio more than 100% (indicating congestion on links)
- Total travel time (pcu-hr)
- Total travel Distance (pcu-km)
- Average speed (kph)

In addition to assessing the congestion levels, emission estimation too is a key indicator of the performance of a scheme. Emissions are estimated by using the equation as shown below adopted from Cai and Xie (2011):

$$ER_a = \frac{\sum_i EF_i * VP_{ia} * v_a}{3600 * L_a} \quad (2a)$$

$$E_a = (ER_a * L_a * 3600)/1000 \quad (2b)$$

$$E = \sum_a E_a \quad (2c)$$

where,

ER_a = emission rate on link 'a' (g/km/s)
EF_i = emission factor of vehicle type 'i' g/km
VP_{ia} = vehicle population of vehicle type 'i' on link 'a'
v_a = running speed of link 'a' kph
L_a = length of link 'a' in km
E_a = emission for link 'a' (kg/hr)
E = total emissions for the entire network (kg/hr)

Link flow from traffic model provides the necessary input to equation (2a) in terms of vehicle population on each link. However it needs to be split by type of vehicle too. In the absence of a multiple user class assignment model which requires specifying mode-wise O-D demands along with relevant generalised cost equations, we have adopted proportions of vehicles from known modal shares within the city of Bandung. Equation (2a) also requires running speed of vehicles which is one of the outputs of traffic assignment model too. Finally length of each link is one of the inputs to traffic network model which is easily transformed to form an input to equation (2a). The emission factors required for each vehicle type are shown in Table 2. Thus all variables in equation (2a) are compiled to compute the emission rates on each road link from which the emissions from each link are computed using equation (2b). Finally summing the emissions from all links (equation 2c) gives the estimate of pollutant emissions in the entire city.

Table 2 Emission factors by vehicle type

Type	CO (g/km)	NO (g/km)
Passenger Car	5.99	0.44
Bus	4.76	4.54
LGV and HGV	6.75	1.77
Motorcycle	13.3	0.85

Source: Wang et al. (2001) cited in Cai and Xie, 2011; Ittipol (2004) cited in Oanh et al. (2008)

4.4 Network validation

Validation process for the model involves comparison between modelled flow, which is generated by SATURN, and the actual traffic count observed in the field. Ideally both the flow values should be equal but in reality they never do. Hence a reality check is performed by comparing the modelled flows with the observed flow and the quality of network model is then measured by using the GEH statistic defined as below.

$$GEH = \sqrt{(V_2 - V_1)^2/(0.5(V_1 + V_2))} \quad (3)$$

where

V_1 = modelled link flow
V_2 = observed link flow

A GEH value of 5% is generally considered acceptable.

Traffic count data from 12 different locations is available for validation purposes although it is far from ideal. The validation result is shown in Figure 7 as follows.

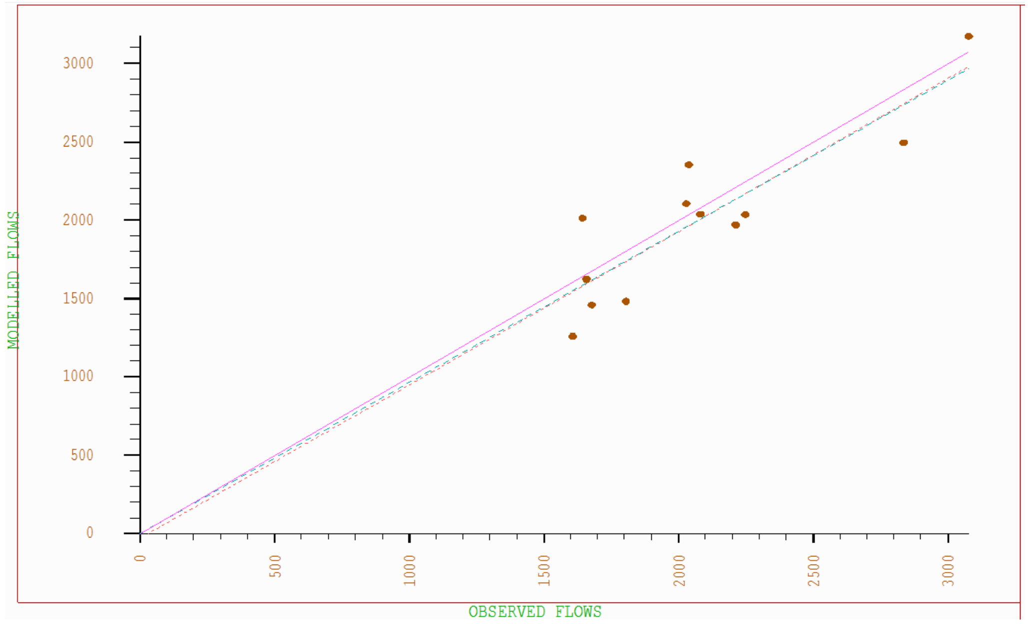

Figure 7 Comparison between traffic counts and modelled flow

For Bandung, four of the modelled links have GEH values less than or equal to 2, which is taken to be 'excellent'. One link has GEH value below 5 which is still acceptable and the rest have GEH values between 5 and 9.17.

As the count data available is too limited we have extended the validation process to check the modelled travelled travel times. Thus the validation process continues to compare the travel time from a particular origin to some destination (generated by SATURN tree analysis) and the actual travel time, which, for this paper, is obtained from Google Maps. Travel times generated by SATURN for six major O-D pairs have been compared with the estimates of time from Google Maps (Table 3).

Table 3 Travel time comparison

No	Origin	Destination	SATURN Average Travel Time (mins)	Google Maps Range of Travel Time (mins)
1	Institute of Technology Bandung	Husen Sastranegara Airport	26.6	14 – 24
2		Bandung Train Station	16.9	8 – 18
3		Bandung City Square	22.2	12 – 18
4		Trans Studio Bandung (Shopping Mall)	22.4	18 – 30
5		Padjadjaran University	51.4	45 – 70
6		Leuwipanjang Bus Station	27.5	27 – 35

It can be seen that four O-D pairs have travel times generated by SATURN within the range of travel time estimated by Google Maps while the other two O-D pairs are outside the range though the difference is small. Although the flow and travel time comparisons could benefit immensely from a rich database of counts/experienced travel times, this model is deemed to be considered as acceptable for the purpose, given the good range of results as estimated by the model.

4.5 Scenario development

Traffic simulation is based on three scenarios: *Do-nothing*, *Car-free day* and *Odd even plate* scenarios. Do-Nothing scenario sets out the benchmark if no scheme is implemented. The results from the car-free day and odd-even plate scheme scenarios are compared with the do-nothing to estimate the impact and to assess how effective those two policies would be. All three scenarios are modelled over a six year period with 2015 as the base year. The simulation results are presented for various years between 2015 and 2021 as indicated below.

Table 4 Modelled policy scenarios

Year	Do-nothing	Car-free day	Odd-even plate number
2015	✓	✓	✓
2018	✓	×	✓
2021	✓	✓	✓

During the modelled period of six years exogenous annual vehicle growth is also taken into account representing the natural growth. Bandung city annual vehicle growth rate is set equal to 5% based on Syabri (2013). Thus the compound growth factor for 2018 will be 1.16 and that for the horizon year 2021 will be equal to 1.34. These growth factors are easily applied in SATURN as uniform factors to project the overall demand level.

5. SIMULATION RESULTS AND DISCUSSION

5.1 Do-nothing scenario

Bandung city is predicted to have a significant increase in flow levels by year 2021 putting more pressure on the limited road capacity. While 161 links of the network (12%) in year 2015 are congested with flow over the capacity (volume to capacity ratio, V/C > 100%), in 2021 this number will be about 339 links or 26% of total network links. Figure 8 shows the spread of over-congested links in Bandung by the year 2021. This is rather a large proportion of over congested links which will have far reaching implication on network performance such as overly long journey times, slow speeds, permanent queueing at junctions and unreliable transport system on the whole.

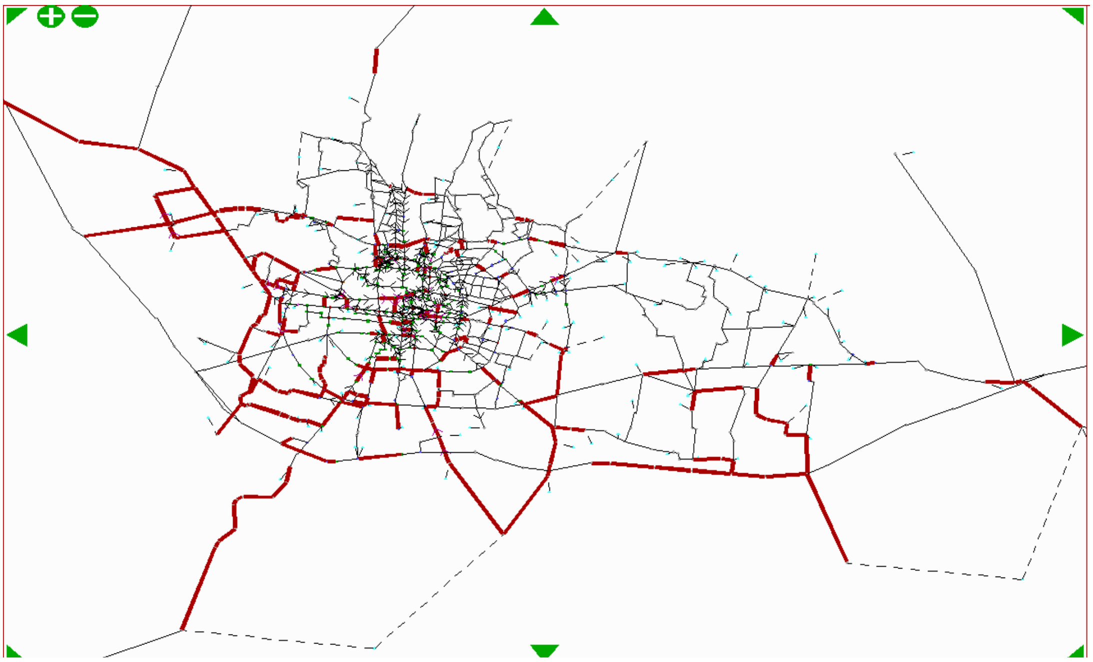

Figure 8 Spread of over congested links in Bandung in 2021 (Do-Nothing Scenario)
(Thick lines indicate over congested road links, while thin lines are less congested though many of them are close to being overcapacity too)

As links in Bandung city are getting congested, overall average speed on the network is decreasing too. The average speed drops from 18.1 kph in 2015 to 12.1 kph in 2021. CO emission over the entire network is expected to increase from 739,565 (Kg/hr) to 844,490 (Kg/hr) by year 2021 (Figure 9). NO emission also follows a similar trend.

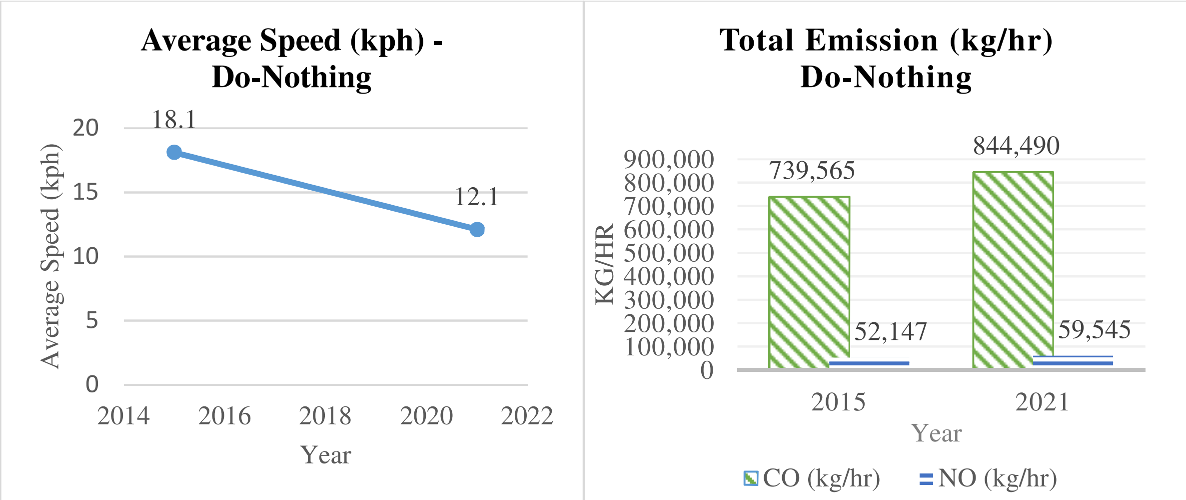

Figure 9 Do-nothing: Speed (left) and Emission Change (right) over time

5.2 Car-free day scenario

Firstly, by comparing the link flows between do-nothing and car free day scenarios, we will be able to assess the impact of car free day on network links. Figure 10 shows the difference in link flows in cordoned area with and without the car free day in year 2015. Green bars in Figure 5 represent an increase in flows while the blue bars represent flow reductions (thickness of the bar is proportional to flow level). It can be seen that there is a significant flow reduction in the road section heading to the car free day area while a number of roads around the restricted section have higher flows. Asia-Afrika Road section with restricted movements of course will have no flow at all under the car free day scenario.

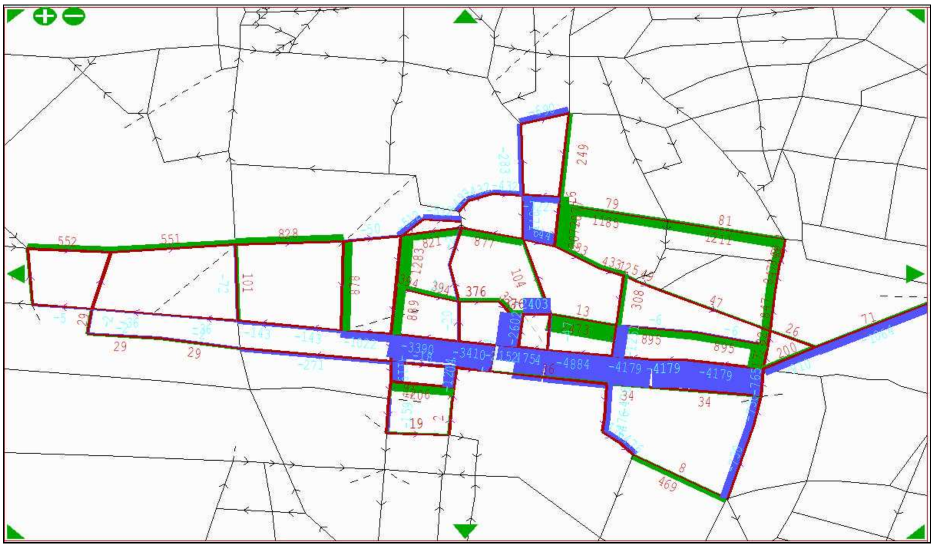

Figure 5 Flow Difference between car-free day and do-nothing scenario, year 2015 (cordoned area)

Please cite this article as: Farda, M. & Balijepalli, C., Case Studies on Transport Policy (2018), https://doi.org/10.1016/j.cstp.2018.07.008

As the number of trips increases from 2015 to 2021 due to natural growth, average speed of overall network naturally declines. Implementing car free day would reduce the average speed to drop by a small margin from 12.1 kph to 12.0 kph (2021). When car-free day scenario is implemented less road space is available in the city centre which then encourages drivers to take alternative routes adding more traffic to the existing flow on those links already operating at high level of congestion themselves. This observation is further strengthened by comparing the total travel time and total travel distance between the do-nothing and car-free day scenarios (Figure 11).

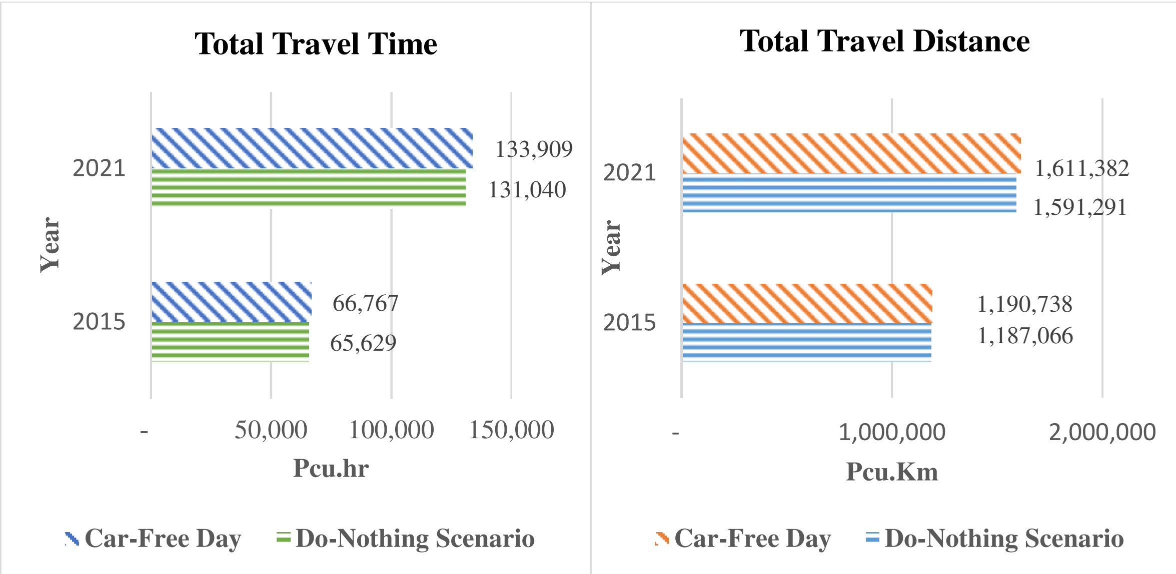

Figure 6 Total travel time (left) and travel distance (right), Do-Nothing Scenario and Car-Free Day

Both total travel time and total travel distance, in years 2015 and 2021, for car-free day scenario are slightly higher than those for do-nothing scenario in respective years. Drivers tend to choose the route with lowest generalised cost which accounts for travel time and travel distance (Koopmans et al., 2013). As their 1st choice route has a ban on it, they now take second best alternative route with slightly higher generalised cost which also may mean higher travel time and higher travel distance. The route choice in this research follows the *equilibrium principle* with drivers revising their routes until they no longer can save time by switching to an alternative route (Wardrop 1952). Thus, the increase of travel time and travel distance indicates significant traffic diversion. Total emissions of CO, also confirm the traffic diversion. In the cordoned area car-free day scenario significantly reduces emission amount compared to do-nothing scenario (Figure 12 right pane). This reduction occurs both in year 2015 and 2021. However, outside of the cordoned area total emission amount is higher if car-free day scenario is implemented which also taken to be a sign of significant traffic diversion (Figure 12 left pane).

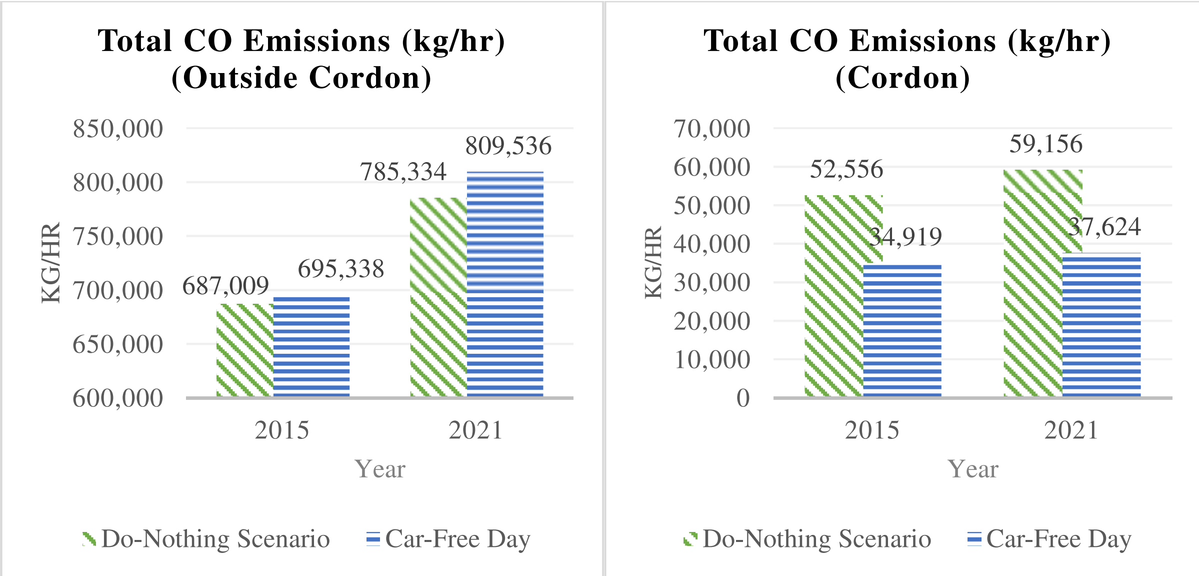

Figure 7 Emissions of CO: do-nothing and car-free day scenarios in outside of cordon (left) and cordoned off areas (right)

If the emissions for both cordoned and outside of cordon area are summed together the result shows that the car-free day scenario yields lower total emissions in 2015 but results in slightly more total emissions in 2021 though (Figure 13 left pane). This result can be explained further by relating this to the emission equations (2a,b,c) and the variables within. As noted earlier, average speed slightly decreases as a result of car-free day implementation. However, referring to Figure 11, car-free day implementation creates traffic diversion as indicated by an increase in total travel distance. This means that more links will now have more traffic flows VP_i, thus making a larger contribution to total emission E (equation 2c). That is to say the reduction in emissions due to reduced speeds is offset by higher proportionate contribution due to an increase in the link flows. Therefore, what really determines E values is the degree of change in link speed and the degree of change in link flows. Also the higher the number of links with increased flows (or speeds) the higher the emissions will be.

To illustrate this point let us consider the relative changes in speed and total travel distance. In year 2015, speed reduces by 2% as a result of car free day implementation (relative to do-nothing scenario), while the travel distance increases by only 0.3% (Figure 11). Therefore, in terms of emission amount E, the speed reduction plays a greater role in determining the emissions compared to the increase in travel distance thus yielding lower emission amount for car-free day scenario. In contrast, in year 2021, speed reduces by 0.8% while travel distance increases by 1.3%. This makes the car free day scenario to generate higher emissions in 2021. This analysis also exposes the limitation of emission equation (2). Decreasing speed does not necessarily reduce emissions, particularly in a highly congested network.

Another indicator of policy performance is the number of links with V/C ratio exceeding 100% (oversaturated links). The do-nothing scenario, in 2015, has only slightly less proportion of oversaturated links compared to do-nothing scenario (Figure 13 right pane). However, by 2021, the congestion is more pronounced with higher proportion of oversaturated links for car-free day scenario than the do-nothing. This means traffic congestion due to diverted traffic exacerbates the congestion due to natural growth in Bandung city. This indicates the need for considering wider transport policy measures to contain the growth in demand.

Please cite this article as: Farda, M. & Balijepalli, C., Case Studies on Transport Policy (2018), https://doi.org/10.1016/j.cstp.2018.07.008

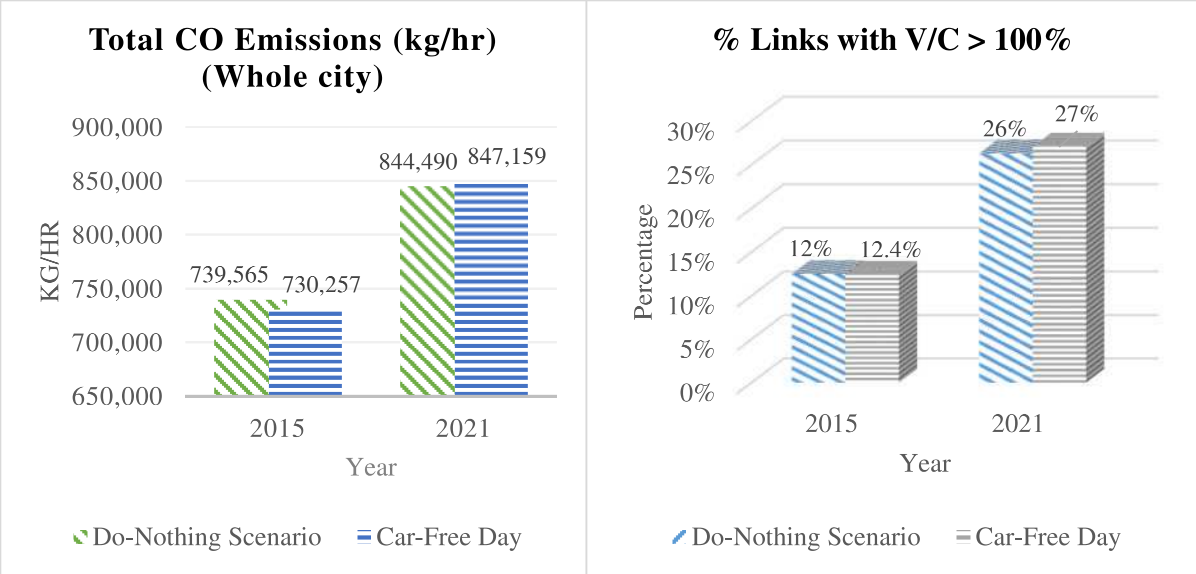

Figure 8 Total emissions (left) and proportion of links with V/C ratio> 100% (right)

Referring back to Figure , there are fewer oversaturated links in car-free day area in year 2021 than in 2015 (not shown in the figure). Looking at Figure 5, thick blue bar around car free day area and less thick green bars on alternative roads mean that the vehicle diversion spreads to several alternative roads rather than a few. Thus in year 2015 the additional pressure on alternative roads is not noticeable compared to the gain in the area of implementation. Those alternative roads still have some spare capacities to embrace the diverted traffic then. However, as the total number of trips rises by year 2021, additional traffic on these alternative roads resulting from car-free day implementation will turn some of the nearly oversaturated road sections to fully oversaturated links. As a result car free day measure creates slightly more proportion of over congested links in the city.

Overall, from the above analysis for the six year period we conclude that the car-free day implementation in Bandung is unlikely to result in a significant negative impact for the whole of the city, but yields some positive outcomes for the area in focus.

5.3 Odd-even plate scenario

In the first year of implementation 55% vehicles are allowed to travel (50% odd or even plated + 5% exemptions) and as the balance 45% of the total cannot travel, this policy succeeds in reducing the traffic flow significantly and improves traffic performance both in terms of speed and oversaturated links. This improvement also has an impact on emissions too. However, as the time goes by, drivers' adaptation to the policy represented by an increasing number of exemptions (as profiled in Figure 5), makes the effectiveness of this policy to fade out. This decline can be seen in the flow difference between do-nothing and odd-even scenario in year 2015 and year 2021 (Figure 14). The bandwidths in Figure 9 show the flow reduction if odd-even scenario is implemented. Flow reduction in 2015 is very significant while only being slight in year 2021.

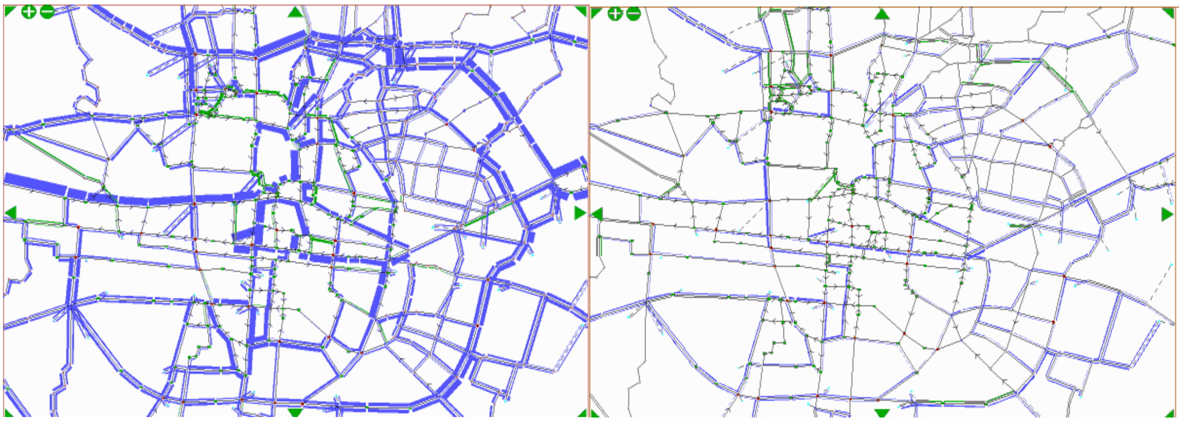

Figure 9 Flow difference between do-nothing and odd-even scenarios in year 2015 (left) and year 2021 (right)

In year 2015, there is a wide gap in the average speed between do-nothing and odd-even plate scenarios (Figure 15). The gap is then closing in gradually through 2018 to 2021. Average speeds for do-nothing scenario and odd-even plate scenario in year 2021 are only slightly different at 12.1 kph and 13 kph respectively while, initially, average speed for those two scenarios were 18.1 kph and 26.1 kph respectively. It is noted that the random slicing method did not have significantly different average speed at 26.4 kph which is very close to the speed as estimated by the naive 50:50 slicing method.

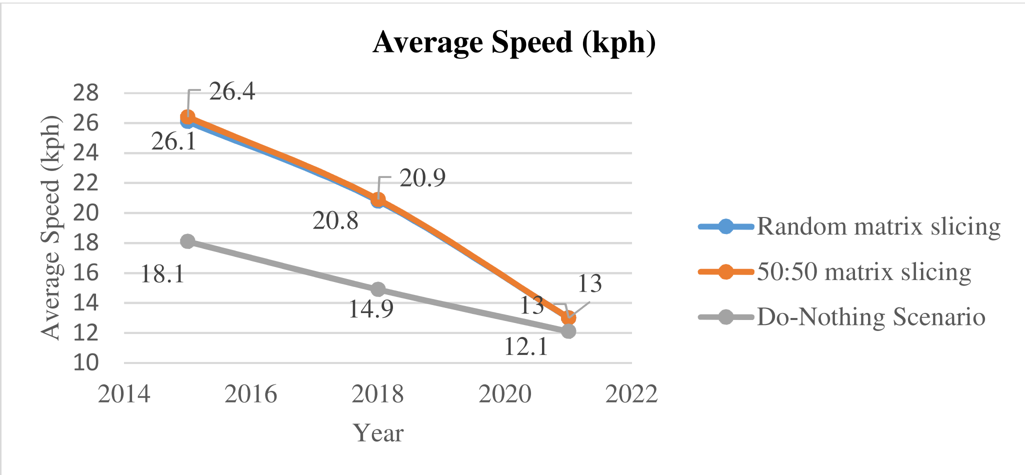

Figure 10 Average speed for do-nothing scenario and odd even scenario

This ‘narrowing gap’ in speed also applies to the rest of the indicators assessed in this paper as they are also a function of the traffic flow. Higher flow gap in 2015 and smaller gap in 2021 makes those indicators behave in the same way as speed. This is shown by total travel time and travel distance as in Figure 11 below.

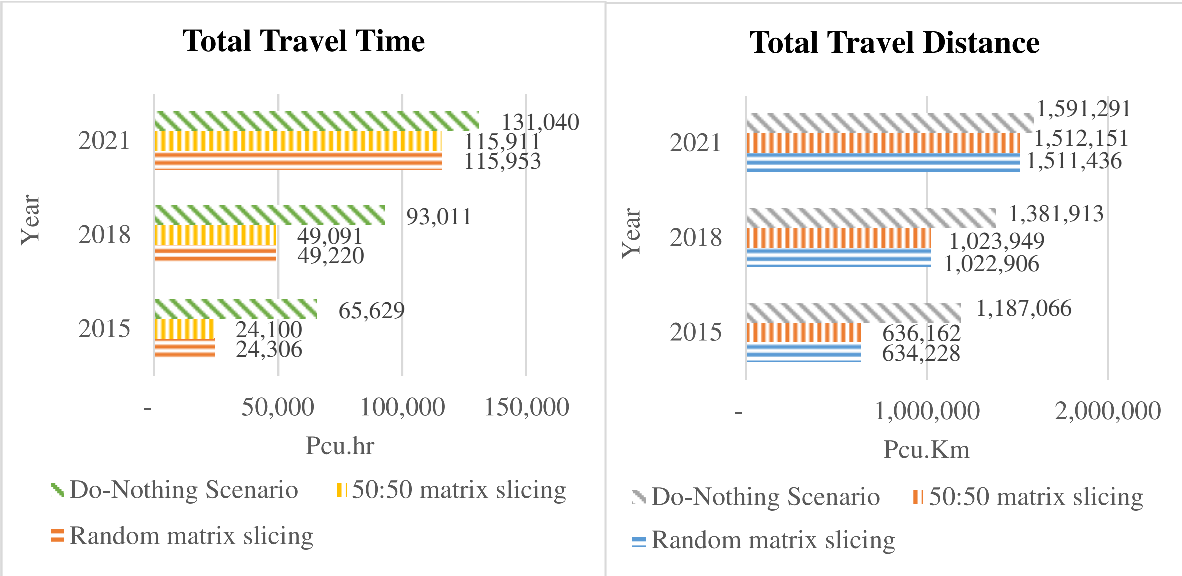

Figure 11 Total travel time (left) and travel distance (right) – Do-nothing scenario and Odd-Even scenario

Similarly, the number of oversaturated links drops significantly, compared to do-nothing scenario, if odd-even measure is implemented. In 2015, only 2% of links are oversaturated. However, in the longer run, namely in year 2021, only slight performance improvement occurs. In 2021, percentage of oversaturated links for odd even scenario is 24% and 25% respectively for random and 50:50 matrix slicing, while 26% of total links are oversaturated if no policy (do-nothing scenario) is applied. This is a very slight but insignificant performance improvement. Total emission amount of both scenarios also follows the same trend (Figure 17).

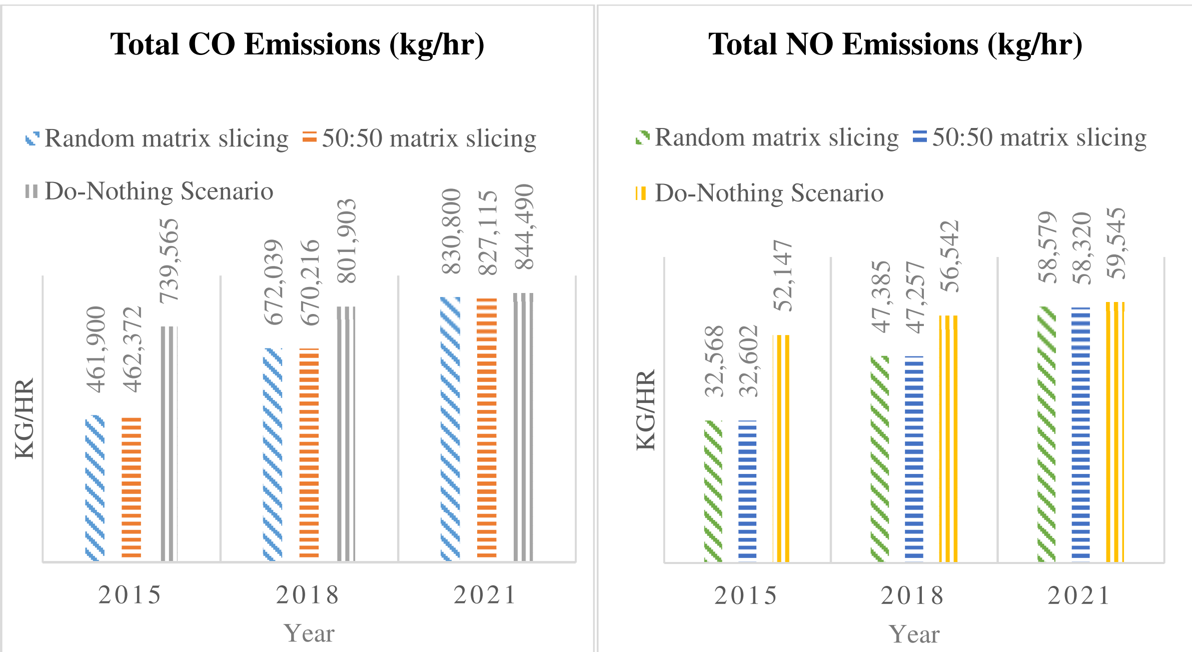

Figure 12 Total CO and NO emissions by do-nothing and odd-even plate scenarios

6. SUMMARY AND CONCLUDING REMARKS

Traffic congestion in cities is caused by natural growth in population together with a positive growth in economy. When traffic flow exceeds the available road capacity, performance of the road network deteriorates. City authorities constantly struggle to tackle congestion and usually rely on capital intensive capacity expansion projects where possible. However it is well known that capacity expansion generates more traffic and thus may not resolve the congestion problem. An alternative way to address this problem is by applying traffic demand management measures which is less capital intensive. This paper explores the use of two demand management measures which have been relatively less understood. Car free day and odd even plate policies have been simulated and impacts analysed in case of Bandung city in Indonesia.

Car free day tends to divert vehicles to alternative routes which need not be efficient in themselves. As a result car free day policy need not necessarily improve the overall network performance. This can result in lower traffic flow, lower emissions around car-free day area but could increase pollution/congestion elsewhere on the network. Simulation of traffic flow in Bandung shows car free day on Asia-Afrika Road during peak hour would deliver average network speeds similar to that by do-nothing scenario. Traffic diversion from car-free day policy results in higher distances travelled by individuals which causes travel time to increase and thus exerts higher pressure on other road sections. In Bandung alternative roads however still can cope with extra traffic load due to diversion during the first year of implementation, however, in the future will result in higher number of oversaturated links. The total emissions also increase by 2021 if this policy is implemented. Considering the results, car free day policy needs to be considered with caution and should be supported by complementary initiatives e.g. public transport improvement.

Odd-even policy offers a compelling result in the short term. However, if this policy is implemented in longer term the performance is likely to gradually decline. All assessed indicators in this study encompassing total flow, average speed, total travel time, travel distance and emission amount show one and similar trend, which is a significant improvement in the beginning but only a slight improvement by the sixth year. Note that the improvement is directly influenced by the vehicle exemption profile, which means that not all, but almost all drivers have adapted to this policy perhaps by owning a second vehicle (by year 6). If all drivers have adapted, this policy may have no impact at all. The adapting behaviour is highly likely especially in Bandung where a motorcycle is easily affordable by many given the easy access to finance. In addition, no significant difference is seen in odd-even scenario assessment with random matrix slicing and the naïve 50:50 matrix slicing. The underlying reason is that even though the number is generated randomly the average of those numbers is still 0.5 which results in no difference for the city as a whole though might result in some local variations across various parts of the city.

There are three major implications to policy from this research which are set out as below:

- Odd-even plate policy would be extremely effective in managing the demand in the shorter run. They could be relied on for managing the traffic during special events such as the forthcoming Asian Games in Jakarta in 2018. However in the longer run, they may not be very effective as the drivers tend to adapt to the restriction in place. Cost of enforcing the measure is also a deterrent to its continuity in the longer run.
- Car free day policy could effectively revitalise the city centres by drawing tourists/visitors due to the improved image in terms of better pedestrian safety as well as being less polluted. This will also help in improving the attitude of residents towards active modes of travel such as walking & cycling. However it is extremely important to analyse the wider network-based effects due to the diversion of traffic.
- This research points out the need to look at integrated planning approach rather than considering transport policy measures in isolation. For example policies such as car free day could be effectively combined with public transport improvements and parking controls. Odd-

even plate policy if implemented in city centre rather than the entire city, could prove very effective if combined with park & ride systems, however, we need to ensure that the through traffic has alternative routes to use.

This research can benefit further by having access to wider datasets e.g. traffic count data through 24-hour period at a number of locations in the city which will help in improving not only the model validation but also will enable projecting the results to 16-hour and 24-hour periods from the peak hour model developed. Secondly the emission model used in this research does not consider the building up and dissipation of queuing which would improve with higher resolution data. Research into driver adaptation behaviour will help in profiling the exemptions in case of odd-even plate policy. Finally odd-even plate policy could be tested over a smaller area of the network such as city centre. Despite the limitations, the research reported in this paper is helpful in understanding the role of relatively cheaper demand management options at least in the short run.

Acknowledgements
The authors wish to express their gratitude to the Indonesia Endowment Fund for Education (LPDP), Ministry of Finance, Government of Indonesia for sponsoring this research. The authors thank the Transportation Laboratory at Institute of Technology Bandung (ITB) for providing the initial datasets on Bandung SATURN network, O-D matrix and traffic count survey data for this research.

REFERENCES

Bandung City Central Statistics Agency 2015. *Bandung City in Figures*. Bandung: Bandung Central Statistics Agency

Cai, H. and Xie, S. 2011. Traffic-related air pollution modeling during the 2008 Beijing Olympic Games: The effects of an odd-even day traffic restriction scheme. *Science of the Total Environment.* **409**(10), 1935-1948.

Cantillo, V. and De Dios Ortúzar, J. 2014. Restricting the use of cars by license plate numbers: A misguided urban transport policy. *DYNA*. **81**(188), 75-82.

Carrier, M. Apparicio, P. Seguin, A and Crouse, D. 2014. Ambient air pollution concentration in Montreal and environmental equity: Are children at risk at school. *Case Studies on Transport Policy* 2(2), 61-69

Dharmowijoyo, D. B. E., Susilo, Y. O., Karlstrom, A. and Adiredja, L. S., 2015. Collecting a multi-dimensional three-weeks household time-use and activity diary in the Bandung Metropolitan Area, Indonesia. *Transportation Research Part A-Policy And Practice,* 80**,** 231-246.

DfT (2014) TAG Unit M3.1, Highway Assignment Modelling, Transport Appraisal and Strategic Modelling Division, Department for Transport, London

Firman, T. 2009. The continuity and change on mega-urbanization in Indonesia: A survey of Jakarta-Bandung Region (JBR) development. Habitat International. 33(4), 327-339.

Georgina Nagy, A.M.E.D.Á.R.T.Y. 2014. Monitoring of air pollution spread on the car-free day in the city of Veszprém. *International Journal of Energy and Environment,* 5(6), 679-684.

Guttikonda, S. and Goel, R. (2013) Health impacts of particulate pollution in a megacity—Delhi,India, *Environmental Development*, 6, 8-20

Institute for Southeast Asian Studies. 2010. *Urbanisation in Southeast Asian Countries*, Pasir Pajang, Singapore, Institute of Southeast Asian Studies

Kanaf, N. and Razif, M. 2010. *The efficiency of car free day program to the reduction of carbon emission*. ITS undergraduate theses. Surabaya: Sepuluh November Institute of Technology

Koopmans, C., Groot, W., Warffemius, P., Annema, J.A. and Hoogendoorn-Lanser, S. 2013. Measuring generalised transport costs as an indicator of accessibility changes over time. *Transport Policy.* **29**, 154-159.

Leo, A. Morillon, D. and Silva, R. 2016. Review and Analysis of Urban Mobility Strategies in Mexico, *Case Studies on Transport Policy*, 5(2), 299-305

Ortúzar S, J. D. D. & Willumsen, L. G. 2011. *Modelling Transport,* Chichester, West Sussex, United Kingdom, John Wiley & Sons.

Ni Putu Decy, A., Negara, I.N.W. and Suthanaya, I.P.A. 2015. Impact Analysis of car free day in Denpasar, Bali – Case study: Puputan Niti Mandala Renon main road. *Jurnal Spektran.* **3**(1).

Standing Advisory Committee on Trunk Road Assessment 1994. *Trunk roads and the generation of traffic*. London HMSO

Subramanian, M. (2016a) Can Delhi save itself from toxic air? *Nature* 534, 166–169 (09 June 2016) doi:10.1038/534166a http://www.nature.com/news/can-delhi-save-itself-from-its-toxic-air-1.20034 web site accessed 26th Sep 2017

Subramanian, M. (2016b) New Delhi car ban yields trove of pollution data, *Nature* 530, 266–267 (18 February 2016) doi:10.1038/530266a, http://www.nature.com/news/new-delhi-car-ban-yields-trove-of-pollution-data-1.19385 web site accessed 26th Sep 2017

Syabri, I. and Pradono, B.T.S., 2011. Embracing paratransit in Bandung Metropolitan Area, West Java, Indonesia.

Van Vliet, D. & Hall, M. 2004. Saturn 10.5: User Manual. Leeds, UK: Institute for Transport Studies, University of Leeds.

Wardrop, J. G. 1952. Some theoretical aspects of road traffic research. ICE Proceedings: Engineering Divisions, Thomas Telford, 325-362.West Java Central Statistics Agency. 2015.