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Research Article

Computation and Optimization of Traffic Network Topologies Using Eclipse SUMO

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Abstract: The advent of modern computational tools in field of transportation can help to forecast the optimized vehicular routes and traffic network topology, using traffic conditions from real world data as inputs. In this study, the topologies of one-way and two-way street networks are analysed using microscopic traffic simulations implemented on the SUMO (Simulation of Urban MObility) platform were performed to analyse the effect of street conversion in Downtown Brickfields, Kuala Lumpur. It was found that one-way streets perform better at the onset of traffic congestion due to their higher capacity, but on average, the four-fold longer travel times make it harder to clear traffic by getting vehicles to their destinations than two-way streets. As time progresses, one-way streets' congestion may become doubly worse than that of two-way streets. This study may contribute to a more holistic assessment of traffic circulation plans designed for smart and liveable cities.

Keywords: Eclipse SUMO; Street Conversion; Traffic Congestion; Traffic Simulation

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1. Introduction

Traffic assignment has been an integral part of urban planning since the proliferation of motorized vehicles in the 1950s. Predicting travel demand and planning the suitable street configuration is necessary to ensure smooth traffic flow and relieve congestion. Modern day civil engineers have adopted the use of advanced computational tools to simulate and optimize traffic flow in the traffic network topology [1-5]. Optimization of traffic flow is also performed via different algorithms [6-10]. One of the most popular traffic computational tool is the Eclipse Simulation of Urban Mobility (SUMO) package [1]. SUMO is a microscopic, multi-modal traffic simulation software that uses the agent-based model approach, whereby each generated vehicle is modelled explicitly, has its route, and moves individually through the network. The vehicles' movements are constrained by a modified Krauss car-following model [11]. SUMO has been used extensively as a computational tool for traffic assignment and traffic modelling and optimization [12-17]. In this study, we have adopted SUMO as a computational tool to study the traffic topology of Downtown Brickfields, which is one of the busiest trade centres at the heart of Kuala Lumpur, Malaysia. Primarily, we wanted to optimize the traffic topology for one of the streets in Downtown Brickfields – Jalan Tun Sambanthan – which is one of the key roads that congest during peak travelling hours. Using SUMO simulation, we will determine the root cause of the congestion and allow the tool to optimize the topology of the traffic network.

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2. Modelling and Methodology

The annual transport statistics of Kuala Lumpur in the years 2010 and 2015 are examined from the various statistical data obtained from various governmental agencies, as listed in Table 1, to estimate the traffic demand of Jalan Tun Sambanthan. At first glance, the registered vehicle population may have grown by 27%, but this statistic from the Ministry of Transport is not a good indicator of growth in travel demand since there is no restriction for non-residents from other states to register their vehicles in Kuala Lumpur.

Table 1. Annual Transport Statistics of Kuala Lumpur

Year	2010	2015	Growth
Resident Population (Millions)	1.67	1.73	3.6%
Vehicle Population (Millions)	3.7	4.7	27%
Rail Transit Passengers (Millions)	134	180	34%
Person Trips to City Centre (Millions)	2.12	2.34	10.4%
Estimated Peak-Hour Traffic Volume of Jalan Tun Sambanthan	1909	2107	10.4%

The growth of rail transit passengers by 34% outnumbered the growth in the resident population of only 3.6%. A better statistic was obtained from the Kuala Lumpur City Hall, which estimated the growth of personal trips to the city centre by 10% from the year 2010 to 2015. As Jalan Tun Sambanthan is also located in the city centre, we assumed the same growth rate estimates and worked out the peak-hour traffic volume to be in the range of 2276 – 3414 pcu in the year 2010 and 2513 – 3769 pcu in the year 2015, respectively. The growth of 10% peak-hour traffic volume at Jalan Tun Sambanthan from 2010 to 2015 would not affect traffic efficiency, as theoretically, a one-way street can improve the traffic capacity by more than 10% [18]. Thus, it may be interesting to conduct a simulation study that can study the effects of the network topology alone, to understand the cause of traffic congestion at Jalan Tun Sambanthan.

The traffic network topology of Downtown Brickfields will be studied using both the macroscopic and microscopic traffic flow model approaches. The macroscopic model allows us to have a general overview of the traffic flow parameters of the network, while the microscopic model is used by the traffic simulation software to generate the traffic scenarios for the flow analysis. For the macroscopic model, we have used the classic Greenshields' traffic flow continuity equation [19], which simply states that the average vehicle speed on a street, u, in kilometres per hour (km/hr), the traffic flow rate, q, in vehicles per hour (veh/hr), and the traffic density, k, in vehicles per kilometres (veh/km), is related by:

$$= k_j \cdot u - \left[\frac{k_j}{u_f}\right] \cdot u^2 \tag{1}$$

where k_j is the free-flowing traffic speed and u_f is the traffic density at congestion. At any given time throughout the simulation, the traffic flow rate can be obtained by manually counting the number of vehicles passing through a designated point on the street, while the traffic density can be obtained by counting the number of vehicles that occupies the whole stretch of the street, and then divided by the length of the street. Alternatively, the simulation software can also obtain traffic flow and density output files. Meanwhile, the average vehicle speed can be directly extracted from the simulation software, which keeps track of each generated vehicle on the map. In our study, we adopted the open-source traffic simulation package Simulation of Urban Mobility (SUMO) [1]. The traffic network of Downtown Brickfields, as can be seen in Figure 1, can then be imported and subsequently used in simulation using Open Street Map (OSM) Web Wizard, which is a tool installed alongside SUMO. The imported urban street network of Downtown Brickfields is shown in Figure 2.

After importing the street network, we modified Jalan Tun Sambanthan into a two-way street using netedit, a graphical network editor included in SUMO. Netedit also allows the creation and removal of streets and the connection and reconnection of paths at intersections or junctions. To generate trips for vehicles, the random trips function of SUMO was used to generate vehicles randomly in the network, which follows the algorithm of the Mersenne Twister [20]. A large number of vehicles will be generated at random positions on the map at the rate of one vehicle per second, which is a number sufficient to drive the traffic network into congestion, forming the baseline traffic activity for the whole map.

In addition to this, in order to analyse the impact of the street conversion of Jalan Tun Sambanthan on traffic flow, in particular, the south-west bound traffic coming from KL Sentral, a calibrator function is deliberately set up along Jalan Rakyat. This calibrator function generates another large number of vehicles at a one-second interval but can also enforce a specific route plan for them. At this generation rate, the total number of vehicles generated in one hour would be around 3600. Thus, this vehicle generation rate can closely mimic the peak-hour traffic conditions as laid out in Table 1. For the one-way street simulation, the vehicles generated by the calibrator function are set to traverse a long detour along Jalan Rozario and Jalan Sultan Abdul Samad to reach Jalan Tun Sambanthan, as shown in Figure-3(a). In contrast, for the two-way street simulation, the generated vehicles can directly enter Jalan Tun Sambanthan, as shown in Figure 3(b).

Figure 1. a) Google Street Maps of Downtown Brickfields, Kuala Lumpur b) Typical traffic at midweek peak hour

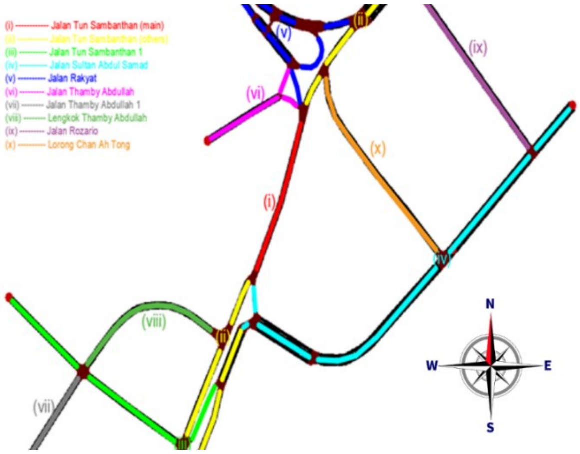

Figure 2. Urban street network of Downtown Brickfields, Kuala Lumpur, imported from OSM.

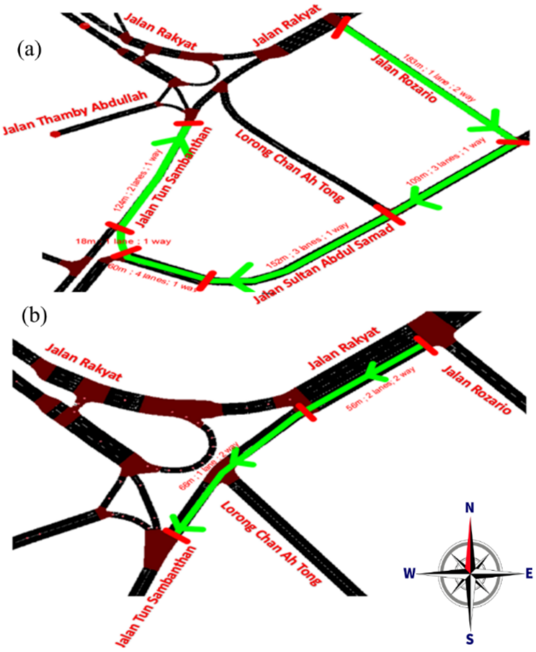

Figure 3. Downtown Brickfields urban street network with Jalan Tun Sambanthan as (a) a one-way street, and (b) a two-way street. The green arrows show the enforced route plan of vehicles generated along Jalan Rakyat.

3. Results and Discussion

We have performed three simulations for both one-way and two-way street traffic in order to estimate the optimised solution. For each simulation, the macroscopic traffic parameters of traffic flow rate and density are obtained by manually counting vehicles at a given time. The only quantity extracted automatically from SUMO is the Aggregate Traffic Speed of the Network, aggregated from all the existing vehicles' movement on the map. As the simulation progresses, these traffic parameters are inspected and recorded at different elapsed times. The results from all three simulations are combined, and the average values are taken and tabulated in Table 2.

Table 2. Dataset of traffic simulation in one-way and two-way street networks

Elapsed Time (s)	Aggregate Traffic Speed of Network (km/hr)	Traffic Flow Rate, q (veh/hr)	Traffic Density, k (veh/km)	Elapsed Time (s)	Aggregate Traffic Speed of Network (km/hr)	Traffic Flow Rate, q (veh/hr)	Traffic Density, k (veh/km)
One-Way Street Network				Two-Way Street Network			
75	29.54	517.89	35.6	75	27.05	842.3	76.5
145	22.44	1268.3	35.6	145	22.31	960.37	92.9
220	18	1139.2	56.76	220	16.63	979.25	98.36
300	16.3	1280.7	66.56	300	12.11	957.91	87.43
370	13.36	993.16	83.08	370	8.05	1065.5	68.31
450	9.61	602.3	117.65	450	5.34	1068.6	73.77
530	6.73	541.28	142.93	530	3.23	1089.2	84.7
600	5.76	400.81	178.53	600	3.16	635.57	133.88

In order to verify the validity of the simulations, we have constructed the time-invariant classic fundamental diagrams of traffic flow, namely the traffic speed-density, traffic speed-flow rate, and traffic flow rate-density relationship diagrams, as shown in Figure-4. The data points plotted in these diagrams all originate from Table 1 for both one-way and two-way street networks and at all elapsed time points. Regression analysis of these data shows that the curves fit very well with Greenshields' empirical model of traffic flow [19], having R-square values of 0.8748 for traffic speed vs density, the value of 0.9245 for speed vs flow rate, and 0.9147 for flow rate vs density, respectively, hence proving a tangible link of the microscopic traffic process giving rise to the macroscopic traffic phenomenon.

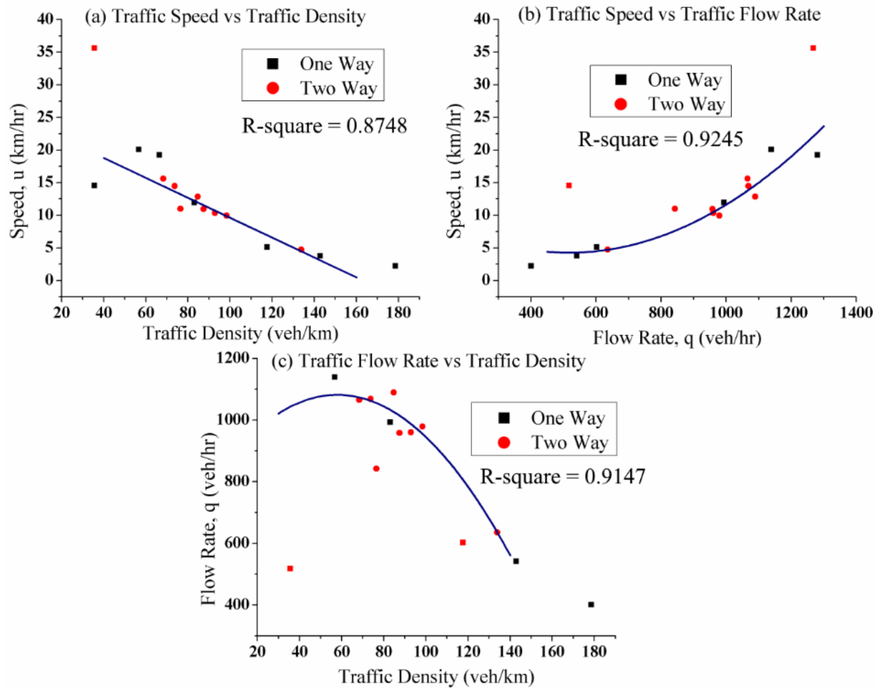

Figure 4. Fundamental diagrams of traffic flow, showing (a) traffic speed vs. traffic density, (b) traffic speed vs. traffic flow rate, and (c) traffic flow rate vs. traffic density. Regression analysis shows that both one-way and two-way traffic data fit well into Greenshields' empirical model [19].

We evaluate the performance of one-way and two-way streets by observing the evolution of the macroscopic traffic parameters over the elapsed time of the simulation. In Figure-5(a), the plot of the aggregate traffic speed shows that there is only marginal improvement in one-way streets compared to two-way streets, but in both cases, the traffic speed decreases over time as traffic congestion builds up. Figures 5(b-c) show a better picture of the evolving traffic scenario over time for each specific enforced route plan. For one-way streets, it is evident that the traffic flow rate is initially very high as the traffic density and number of vehicles on the route are low. One-way streets, true to their high traffic capacity due to longer travel distances, can defer traffic congestion by dispersing traffic to neighbouring areas.

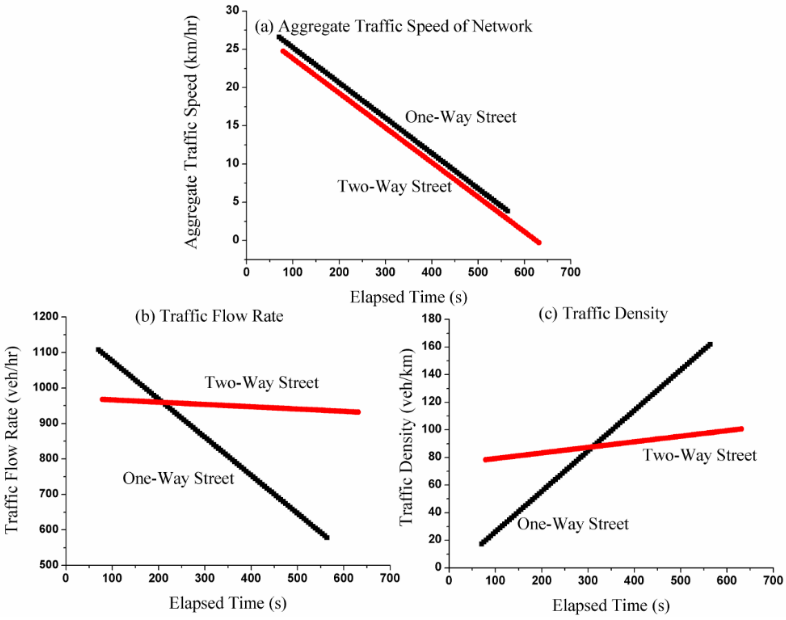

Figure 5. Analysis of traffic situation evolution over time for (a) aggregate traffic speed of the network, (b) traffic flow rate of the route, and (c) traffic density of the route.

This is This is clearly shown in Table 3, where the number of vehicles on Jalan Tun Sambanthan is noticeably smaller when it's a one-way street, and the vehicles are being dispersed to Jalan Sultan Abdul Samad and Jalan Rozario, which have increased vehicle numbers. However, longer travel distances also mean that drivers would also have to take a longer time to arrive at their intended destinations, resulting in accumulation of traffic that leads to congestion. As can be seen from the graphs, as time progresses in the simulation, there is a steep decrease in the traffic flow rate, accompanied by a steep increase in traffic densities.

Table 3. Number of vehicles at steady-state for selected streets

Street	Two Way	One Way	Difference
Jalan Tun Sambathan (main)	29	25	4
Jalan Tun Sambathan (others)	58	48	10
Jalan Tun Sambathan 1	21	13	8
Jalan Sultan Abdul Samad	63	71	-8
Jalan Rakyat	19	11	8
Jalan Rozario	20	33	-13
Lorong Chan Ah Tong	18	10	8

Table 4. Traffic clearance time for one-way and two-way street networks

One Way Street (0.646km)								
Elapsed Time (s)	**75**	**145**	**220**	**300**	**370**	**450**	**530**	**600**
Aggregate Traffic Speed (km/hr)	29.54	22.44	18.00	16.30	13.36	9.61	6.73	5.76
Trip Completion Time (s)	78.7	103.6	129.2	142.7	174.1	242.0	345.5	403.75
Two Way Street (0.122km)								
Aggregate Traffic Speed (km/hr)	27.05	22.31	16.63	12.11	8.05	5.34	3.23	3.16
Trip Completion Time (s)	16.2	19.7	26.4	36.3	54.6	82.2	136.0	139.0
Completion Time Ratio	4.86	5.25	4.89	3.93	3.19	2.94	2.54	2.9

In contrast, two-way streets, having smaller traffic capacity, start with a significantly lower traffic flow rate and a much higher traffic density. Nevertheless, the shorter route plan enabled a higher rate of clearing traffic as drivers could reach their destinations faster. The traffic flow rate and density remain relatively constant as the traffic scenario evolves over time. In Table 4, we have recorded the trip completion time for vehicles travelling in each route at different elapsed times of the simulation. As expected, the one-way street network having a longer travel distance of 0.646 kilometres has a consistently longer travel time, compared to the two-way street network with a shorter travel distance of only 0.122 kilometres. On average, the trip completion time of the one-way street route plan is four times longer than the two-way street route plan.

4. Conclusions

In our simulation analysis of the street configuration in Downtown Brickfields, Kuala Lumpur, we have clearly shown that one-way street networks may not always be more efficient than two-way street networks, but they depend on the traffic scenario that evolves over time. One-way streets allow higher traffic flow rates and lower traffic densities by spreading out the traffic to neighbouring streets and thus perform better at the onset of traffic congestion. However, this higher traffic capacity also served as a double-edged sword in prolonging travel times and accumulating traffic, eventually leading to congestion. On the other hand, two-way streets have a higher traffic clearance rate and thus have a more stable traffic flow rate and density parameters, notwithstanding the lower initial traffic flow and higher densities.

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