Simulating and Validating the Traffic of Blackwall Tunnel Using TfL Jam Cam Data and Simulation of Urban Mobility (SUMO)

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Abstract

Blackwall Tunnel is one of the most congested roadways in London. By simulating the tunnel and the connecting roads, information can be obtained about the traffic conditions and bottlenecks. In this paper, a model will be created using the Simulation of Urban Mobility (SUMO) tool and traffic flow data gathered from Transport for London (TfL) traffic cameras. The result from the simulation will be compared to the journey time data of Blackwall Tunnel in order to determine the accuracy of simulation.

2012 ACM Subject Classification Information systems → Traffic analysis

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Supplementary Material *Software (Source Code)*: `github.com/Chukun-Leo-Gao/Blackwall_Simulation_GIScience` archived at `swh:1:dir:0242fb03acf02ee8c6e971fb8a26814719ac1a1a`

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1 Introduction

Traffic simulation software is a very powerful tool for such requirement. In the last decade, open-source traffic simulation has been developing at a rapid pace, such as Simulation of Urban Mobility (SUMO) [1], an agent-based traffic simulation program developed in 2001 by the German Aerospace Centre. In this case, SUMO will be utilised to construct a model of Blackwall Tunnel and its connecting roads.

Simulation needs to be supported by – or at least validated against – real and accurate traffic data. Fortunately, Transport for London (TfL) provides traffic camera footage that can be accessed via an API [4]. Traffic camera footage can be an incredibly versatile tool for analysis. It can be utilised for recognition of car makes and models [6]. Calculation of traffic flow count from camera footage has also been carried out [5]. Therefore, TfL traffic camera footage will be used to generate traffic data for the simulation in this paper.

2 Case Study

2.1 About Blackwall Tunnel

Blackwall Tunnel is one of the earliest road tunnels under River Thames in London. It was constructed in 1897, initially with two lanes. It was doubled in 1967, and the current Blackwall Tunnel is operating with four lanes in total [7]. The tunnel is currently one of the most congested Thames crossings in London, and a supplement, the Silvertown Tunnel, is now under construction [3]. Therefore, trying to understand the current bottleneck of Blackwall Tunnel will be very helpful for future traffic management of Silvertown Tunnel.

2.2 Literature Review

There have been many attempts at simulating and validating traffic flow in multiple scales, ranging from a whole country to a single motorway. Two main methods are employed. Numerical simulation, as name implies, uses numerical traffic models to estimate traffic flow [8] and are usually limited to one road alone [11]. Agent-based traffic simulation is more versatile. SUMO, as an agent-based traffic simulator, has been put in use in many projects, from small scale simulation such as Bologna city centre [10] to scenarios on a grander scale such as the whole of Luxembourg [2]. However, there has been no previous works on traffic validation of a major roadway using agent-based traffic simulation, so this research fills an important gap within the literature.

3 Methodology

3.1 Constructing the model for SUMO

According to TfL, the Blackwall Tunnel and its approach, dubbed " Blackwall Thoroughfare" , extends from Bow Interchange (Junction with A11) to the north to Sun in the Sands Roundabout (Junction with Shooters Hill Road), stretching a total of approximately 6.9km. In order to compare simulated travel time data with real data from TfL, the main road from Bow Interchange to Sun in the Sands Roundabout, along with slip roads and connecting junctions, should be modelled.

SUMO is supported by a package of powerful tools. In particular, it can read road networks from Open Street Map (OSM), and import the map into NETEDIT program, which is the built-in network editor for SUMO. For this research, Blackwall Thoroughfare and its connecting roads are imported from OSM, and modified to increase realism, including positions and numbers of lanes, shapes of junctions, and placement and timing of traffic lights. The Blackwall Thoroughfare in Google Earth and the same road imported into SUMO NETEDIT can be seen in Figure 1 below.

3.2 Extracting data from TfL Traffic Camera Footage

TfL traffic cameras, or Jam Cams as they are internally known in TfL, provide 10-second footage at 352×288 resolution of live traffic flow. Footage is usually updated once per 5-10 minutes. The Blackwall Thoroughfare is very well covered by Jam Cams, so traffic estimation from the cameras will be relatively accurate.

For this research, all the Jam Cam footages along Blackwall Thoroughfare between 7:30am and 9:30am on all weekdays between 5th and 16th of December for a total of 10 days. As Blackwall Tunnel is the most congested during weekday mornings, the simulation will try to replicate the most stressful condition of the tunnel.

After gathering all the video footages, they are analysed using the " virtual loop" method [13]. Like a traditional traffic induction loop that count cars by detecting magnetic field changes [9], the function of a virtual loop is to count passing vehicles. Firstly, an object detection algorithm, Yolo-v7, is applied to all the Jam Cam footages [12]. Then, a virtual loop, effectively a line drawn across the road in the video footage, is applied, and the number

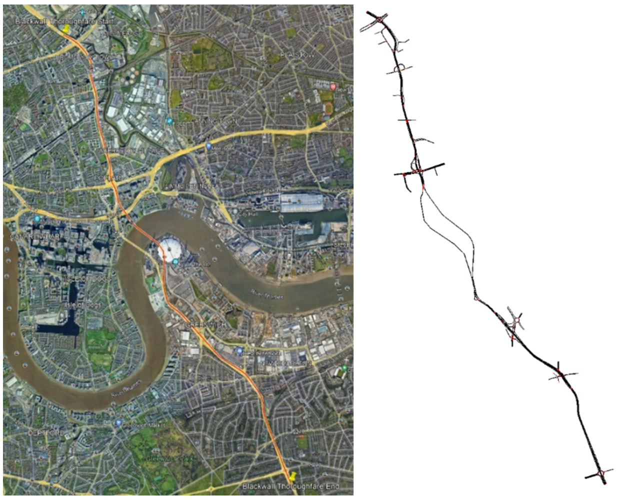


Figure 1 Blackwall Thoroughfare, Google Earth (left) and SUMO NETEDIT (right).

Figure 2 Typical frame of a TfL Jam Cam footage.

of cars that passes through the loop is then counted. In the image below, the white line represents the virtual loop, and if the coordinate of the bounding box of a car moves across the white line, the vehicle will be counted.

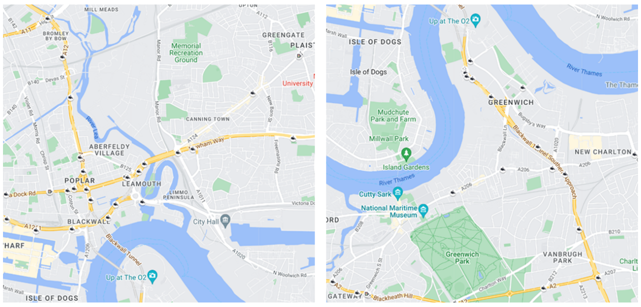
3.3 Simulation Results

After calculating average traffic flow for every Jam Cam, an Origin-Destination Matrix (OD Matrix) is created for the network, and it serves as the input of traffic simulation in SUMO. The ratio of different vehicle types is shown in the table below. As Blackwall Tunnel has a 13ft (4.0m) height restriction, there are almost no articulated lorries and only a few rigid lorries crossing the tunnel.

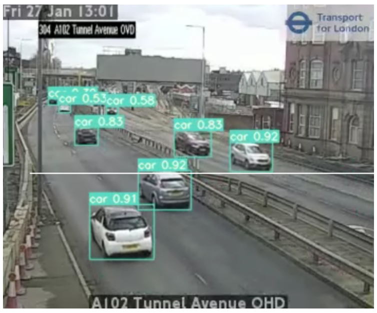
Table 1 Ratio of vehicle types.

Types	Private Car	Van	Lorry	Articulated Lorry	Motorcycle
Ratio	70%	15%	5%	0%	10%

To further increase the realism of simulation, the departure speeds of the vehicles are randomised. The range of departure speeds of private cars is between 90% and 110% of road speed limit, while lorries are lower (between 70% and 90% of speed limit).



■ **Figure 3** Jam Cams along Blackwall Thoroughfare (north/south of Thames), each camera symbol is a Jam Cam.



■ **Figure 4** Application of object detection algorithm and virtual loop.

4 Results and Validation

4.1 Simulation Results

As the published travel times are only available for the full length of Blackwall Thoroughfare, only the vehicles travelling from the beginning to the end of Blackwall Thoroughfare is accounted. As TfL journey time data only includes small vehicles, private cars and vans are included in the travel time analysis. In the simulation, 277 cars and vans traverse the Thoroughfare in the northbound direction and 194 traverse in the southbound direction.

In Figure 5, the horizontal axes represent departure time of vehicle after simulation starts, and vertical axes represent time taken to traverse the entirety of Blackwall Thoroughfare. Several phenomena can be observed from the figure. Firstly, the northbound direction traffic takes a lot longer to traverse the Blackwall Thoroughfare, with northbound journey times reaching over 40 minutes, while southbound journey times are within 20 minutes. This is due to a chokepoint at the northbound entrance of Blackwall Tunnel, where three lanes of traffic merges into two. This chokepoint can propagate congestion for more than a mile. The simulation replicates the congestion propagation, which is a positive sign that indicates the simulation can realistically represent real life traffic phenomenon. Secondly, in both northbound and southbound direction, the journey time first remains low, and then gradually increases as simulation progresses. This also happens in real life. During the first several minutes of peak hour (around 7am), the traffic increases drastically, causing congestion.

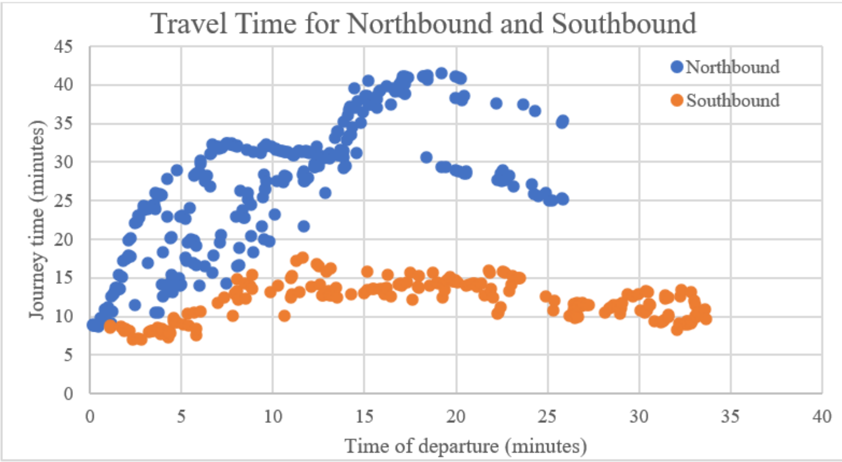


Figure 5 Journey time with regards to departure time in northbound and southbound direction.

4.2 Data Analysis and Validation

TfL has ceased publishing road journey time data since 19th of May 2021, several days after the easing of the last lockdown. Pre-Covid data, taken from the workdays of the first week of December 2019 (2nd – 6th), will also be provided for comparison. Moreover, TfL provides data for 90th percentile travel time of Blackwall Tunnel, albeit the data was published in 2017. Although it is slightly too outdated for this research, it has been included as a third point of validation.

Table 2 Comparison of simulation data and TfL journey time data.

Travel Time	Unit: Minutes	Average	Standard Deviation	90th percentile
Simulation (December 2022)	Northbound	26.8	8.8	39.3
	Southbound	11.9	2.5	15.0
TfL Data (May 2021)	Northbound	23.7		
	Southbound	8.6		
TfL Data (December 2019)	Northbound	23.9		
	Southbound	10.4		
TfL Data, 90th percentile (2017)	Northbound			52.9
	Southbound			12.9

Apart from travel time, speed is another measurement for traffic simulation. Although TfL does not provide speed data to validate against, it is a better indicator for congestion, and the distribution of speed can help visualise driver behaviour in the simulation. The average speed and 90th percentile for northbound and southbound directions are shown in the table below, and the distributions of northbound and southbound speed are shown in Figure 6.

5 Discussion of Data

The simulation corresponds quite well with TfL data from 2019, but less so with data from 2021. The average travel time deviates from 2019 data by 0.4 standard deviation (12%) in northbound direction, and 0.6 standard deviation (13%) in southbound direction. For the 90th percentile, simulated value is 35% lower than the real value in northbound direction, and 14% higher than the real value in southbound direction.

Table 3 Speed distribution of Blackwall Thoroughfare (lower speed indicates longer journey time).

Speed	Unit: mph	Average	Standard Deviation	90th percentile
Simulation	Northbound	12.1	5.9	20.4
(December 2022)	Southbound	22.1	5.0	30.1

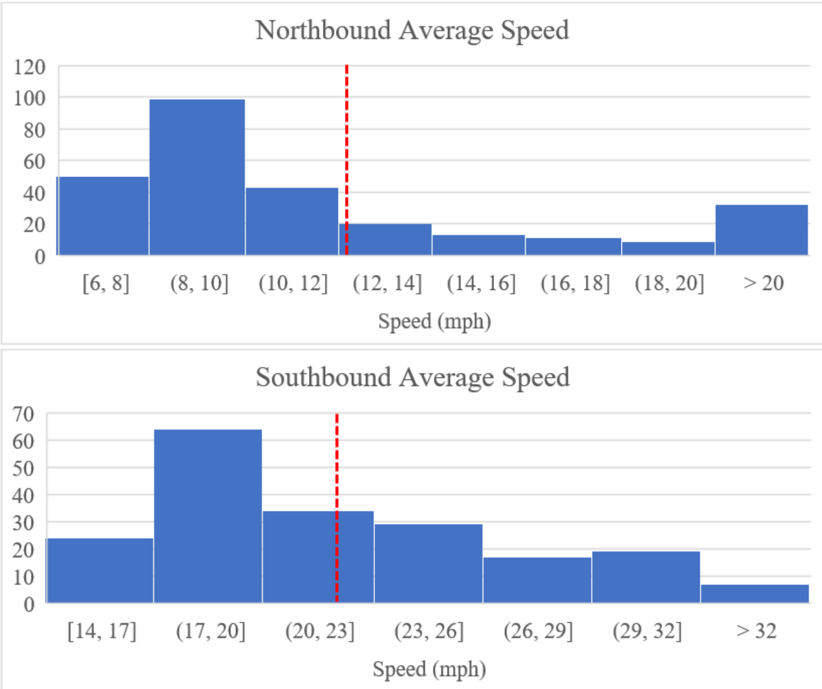


Figure 6 Histogram of northbound and southbound average speeds, with red dashed lines denoting the average.

Some insights can be uncovered from the journey time data. First of all, the simulation result is closer to December 2019 than May 2021, showing that the vehicle traffic on the Blackwall Thoroughfare has not yet recovered in May 2021, but has since returned to or even exceeded pre-Covid level in December 2022. Secondly, although the real averages are well within one standard deviation from the simulated values, the overestimates, which are over 10% in both directions, cannot be ignored. This discrepancy can be explained by several factors: TfL Jam Cam data comes in 10-second clips, and can be easily biased. It is possible that by using multiple short clips, traffic flow is overestimated. Also, some important interchanges (e.g., the interchange with Devas Street and Twelvetrees Crescent, see Figure 7) are not covered by any TfL Jam Cams, and traffic flow through the ramps could be overestimated.

Although the 90th percentile data is very old, it can still provide some valuable knowledge. The percentage of overestimate in southbound direction (14%) is similar compared to that of average travel time (13%), meaning the discrepancy might be caused by the same underlying reason. Meanwhile, the simulation severely underestimates the 90th percentile in the northbound direction. It can be caused by accidents in the northbound direction: the " 3 into 2" merging at the northbound entrance of Blackwall Tunnel have caused quite a few rear-end collisions in the past year, and accidents can cause further delays. The simulation does not account for accidents, and thus underestimates travel times in extreme cases.

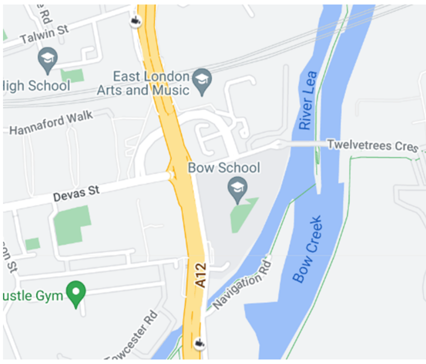


Figure 7 No Jam Cams at the interchange with Devas Street and Twelvetrees Crescent.

Some information could also be gleaned through histograms of average speed. The northbound average speed follows a long tail distribution, with three quarters of cars fall below average speed. Higher speeds correspond to earlier departures, prior to the formation of chokepoint at the northbound entrance of Blackwall Tunnel. However, in the southbound direction, less than 60% of cars fall below average speed, indicating that there is hardly any " early start advantage" on the southbound direction, as there are no chokepoints. This discrepancy is already visible in Figure 5, but Figures 6 and 7 makes it much clearer.

6 Conclusion

In this paper, the Simulation of Urban Mobility (SUMO) tool is used to model the Blackwall Thoroughfare, and the results correspond reasonably well to the data provided by Transport for London (TfL). The simulation slightly overestimates the journey times by approximately 10%, but are well within one standard deviation. This is likely due to the short length of Jam Cam videos and improper Jam Cam coverage. One key gist of this paper is that a large amount of data needed for an accurate agent-based simulation. Without a full picture of the Blackwall Thoroughfare, the simulation will inevitably deviate from reality.

In the future, the author plans to obtain longer videos and videos from junctions without Jam Cam coverage. The footage will be used to determine the traffic within each junction, calculate speed and acceleration distribution, and observe driving behaviour such as lane changes. By incorporating these elements into the simulation, each car agent will become more heterogeneous, thus better mimicking behaviour of real-life drivers. It is hoped that increased heterogeneity will result in a more realistic simulation result.

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