Analysis of Non-motorized Vehicle Traffic Flow in Tsinghua University and Comparison with External Roads

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Abstract. Universities in China adopt closed planning layout basically. The demand for non-motorized vehicles is strong and the traffic characteristics are prominent, which is different from the conditions of external roads. Considering the availability of surveillance video in Tsinghua University and the convenience of observing the traffic environment, this paper takes roads on campus as the objects to analyse the characteristics of its non-motorized traffic and make comparison with external ones. The results of campus traffic will not only help us understand the current situation and improve traffic safety, but also provide a basis for solving traffic problems in similar spaces such as unit courtyards, residential quarters, etc..

1. Basic introduction of non-motorized vehicle traffic in Tsinghua University

The campus of Tsinghua University is located between the 4th-North Ring and the 5th-North Ring in Haidian District, Beijing. It covers an area of 356 hectares and has a construction area of 1.68 million square meters. As of December 31, 2018, the school has a total of 15,708 faculty members and 48,739 students [1], which belongs to the scale of a giant campus [2].

The main body of campus traffic is divided into three parts: pedestrians, non-motorized vehicles and motorized vehicles. Non-motorized vehicles used by most students and employees involve bicycles and electric bicycles. The traffic space is mainly composed of roads, square and parking lot. Transportation facilities are the infrastructure for organizing and managing traffic, including traffic lights, traffic signs, speed bumps, etc..

We often pay more attention to zoning planning, building structure, and landscape design than road system and traffic management when laying out campus [3]. Tsinghua University is about 5.9km in length, and the widest from east to west is about 4.75km. The campus also tends to merge similar functions and facilities simply as Figure 1 shows. The purple area for teaching and research, the blue are for students, and the yellow area for employees are obviously divided into block. Such clear zoning method leads to a long daily travel distance when the campus is large. The most common commuting is between the students' dormitory and the teaching buildings and research offices. The distance between the two area is usually more than 1km, exceeding comfortable walking distance as 400m [4]. However the red and blue routes of shuttle buses does not cover that. So most students rely on non-motorized vehicles to travel.

2. Statistical analysis of non-motorized vehicle traffic flow in Tsinghua University

Most users of non-motorized vehicles on campus are students. Their trips are divided into group activities such as going to classroom and cafeteria, and individual activities such as scientific research and playing sports. Because of the variability and randomness of individual activities, we aim at group activities when studying campus traffic. Figure 2 shows the main roads on campus like a checkerboard
pattern. The red star represent the sixth and third teaching buildings which organize most courses. The orange star represent the Zijing living area with most students. Their relative positions determine the staple traffic line. Between them, Xuetang Road and Xinmin Road are necessary with heavy traffic flow. In order to obtain representative and non-overlapping data, the surveillance videos of corresponding locations from security office are retrieved. Then this paper trains the multi-target tracking deep neural network to automatically identify data such as transit time, non-motorized vehicle type, speed, etc., instead of manual operation to achieve traffic surveys.

Figure 1. Campus map of Tsinghua University.

Figure 2. Main roads of campus.

Volume is counted as shown in Figure 3 for 10 minutes before class, 15 minutes between classes, and 10 minutes after class from April 8 to April 10 in 2019 according to daily routines. The traffic trends of the two sections are basically same. The traffic flow is intermittent, and generally concentrated in a short period of time, with peaks before class, between classes, and meals. It is tidal, which means the direction of main flow is opposite before class and after class from the public teaching building. The reason why the flow is higher after school is that students who go to the laboratory generally do not travel during the peak period in the morning, however, the meal time is almost the same as others. Xuetang Road is located in the middle and connected to more teaching and research buildings, resulting in crowder traffic.

Figure 3(a). Peak volume statistics of Xinmin Road.

Figure 3(b). Peak volume statistics of Xuetang Road.

Figure 4 comes from one-hour surveillance video from the two sections mentioned above and external roads (Shuangqing Road, Xueqing Road). The proportion of bicycle trips on campus is 95.8%, as electric bicycles is 4.2%, and electric tricycles are ignored. The proportion between bicycles and 1 SSM stands for Xinmin Road (Schwarzman College), XTL stands for Xuetang Road (the 3rd—4th teaching building). SQL stands for Shuangqing Road. XQL stands for Xueqing Road. b stands for ordinary bicycles. eb stands for electric bicycles, and tb stands for electric tricycles.
electric bicycles is significantly higher than 56.75% and 37.3% of external roads. The main reason is that the riding distance in the school is still within the physical strength, leading to moderate demand. Moreover, the charging of battery is strictly prohibited at any place since it has caused many fire accidents before, which restricting the purchase and use of electric vehicles by students effectively.

![Figure 4. Statistics of types of non-motorized vehicles on road sections.](image)

Table 1 lists the statistical characteristics of speed. The average speed and standard deviation is reduced, and the distribution is more concentrated because the proportion of electric bicycles on campus is very low. When the bicycles and electric bicycles are considered separately, its mean and standard deviation are lower, to which the explanation is riding on campus is more crowded than external roads and tends to form groups during peak period. Male and female students often share the same vehicle types, the same purpose of travel, and shorter riding distances so that the difference is smaller.

| Road   | Mean speed and standard deviation (km/h) | Mean speed and standard deviation of bicycles (km/h) | Mean speed and standard deviation of electric bicycles (km/h) | Mean speed and standard deviation of male (km/h) | Mean speed and standard deviation of female (km/h) |
|--------|------------------------------------------|-----------------------------------------------------|-----------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| SSM    | 11.82 2.34                               | 11.67 2.17                                         | 13.99 3.53                                                | 12.17 2.34                                    | 11.41 2.19                                    |
| XTL    | 10.96 1.27                               | 10.81 1.27                                         | 11.78 1.15                                                | 11.19 1.26                                    | 10.49 1.13                                    |
| average| 11.29 1.81                               | 11.24 1.72                                         | 13.39 2.34                                                | 11.68 1.80                                    | 11.05 1.66                                    |
| SQL    | 18.67 5.13                               | 14.67 3.59                                         | 21.38 5.13                                                | 19.07 5.26                                    | 14.79 4.34                                    |
| XQL    | 16.07 5.07                               | 14.36 3.22                                         | 19.24 6.26                                                | 17.19 5.61                                    | 14.55 3.76                                    |
| average| 17.37 5.1                               | 14.52 3.41                                         | 20.31 5.70                                                | 18.13 5.44                                    | 14.67 4.05                                    |

3. Speed distribution model of non-motorized vehicle traffic flow in Tsinghua University

Kolmogorov-Smirnov univariate goodness-of-fit tests of four common distributions as normal distribution, lognormal distribution, gamma distribution and Weibull distribution (conclusion at the 5% level) for individual vehicle speed on four sections are conducted. The results are shown in Table 2(at 95% confidence). None of them is suitable for most situations.

| Road | Normal distribution | Lognormal distribution | Weibull distribution | Gamma distribution |
|------|---------------------|------------------------|----------------------|--------------------|
| SSM  | Not excluded        | Excluded               | Excluded             | Not excluded       |
| XTL  | Excluded            | Not excluded           | Not excluded         | Excluded           |
| SQL  | Excluded            | Excluded               | Excluded             | Excluded           |
| XQL  | Excluded            | Excluded               | Excluded             | Excluded           |

Considering non-motorized vehicle traffic is a mixed flow with heterogeneity, the distribution curve may change from a single-peak to a multi-peak distribution. So the mixed Gaussian model with more parameters probably simulate better. When determining the model components, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) are introduced instead of enumeration [5].
Then the maximum expectation algorithm is used to estimate the parameters. The graphs are drawn in Figure 5 (a) ~ Figure 6 (d), and the numerical results are recorded in Table 3.
The individual vehicle speed on SSM conforms to the normal distribution. XTL resembles the normal distribution while more in line with the binary mixed distribution. Both SQL and XQL are binary Gaussian distributions. The reason for the difference of SSM is that the non-motorized vehicle on campus are mostly bicycles and bilateral traffic jam on SSM is not as obvious as on XTL, which means some students choose to ride on the opposite side when unilateral traffic is crowded, causing the density of positive side to reduce. So SSM with a single vehicle type conforms to the normal distribution. The more crowded XTL forms a mixed distribution. However, XTL with a single vehicle type presents similar results as SQL and XQL. The explanation is that the components are integrated by different flow states rather than vehicle types.

4. Velocity-density model of non-motorized vehicle traffic flow in Tsinghua University

The current logistic model of non-motorized vehicle traffic flow [6] is directly derived from the mathematical transformation, lacking a bridge to the traffic situation. Based on the principle assumption of two-dimensional logistic model, the velocity-density model is concluded as equation (1), derived from the characteristics of traffic flow, among which the first is \( v(k)_{k \to 0} = v_f \) (when the density is very small, the speed is expressed as free flow), the second is \( v'(0) = 0 \) (when the vehicle is driving freely, the interaction is ignored), the third is \( v(k)_{k \to k_j} = 0 \) (the driving speed is zero as reaching the jam density), the fourth is \( v'(k) \leq 0, 0 \leq k \leq k_j \) & \( 0 \leq v \leq v_t \). \( v_m \) stands for the ideal value of the maximum velocity in the samples. \( v_f \) is the free flow velocity, and \( a \) is a shape parameter.

\[
v(k) = \frac{v_m}{v_f} \left( \frac{v}{v_f} - 1 \right)^a + 1
\]

Before establishing the model, it is necessary to draw a traffic scatter plot, where statistical time interval needs to be determined. The principle is that the measurement attributes are not sensitive to the change of a single object while retaining the characteristics for researching [7]. Zhou Dan [6] proposed 10–20 seconds is reasonable when counting the number of saturated vehicles in the non-motorized traffic flow. After the observation of videos, this article selects a 15-second interval to calculate the average speed and density for plotting. Since the data in high-density area is more difficult to observe than the low-density area, weighted least squares listed in formula (2) is used as the optimization error.
for fitting to cope with data unbalance. \( v(k) = \frac{v_m}{(\frac{v_f}{v_m} - 1)e^{\frac{v_m}{v_f}k+1}} \), \( v_f > 0, v_m > 0 \). There are \( n \) scattered points in total and \( w_i \) is the weight of point \((k_i, v_i)\) indicating the tendency of sample selection.

\[
\min E(v_f, v_m, a) = \sum_{i=1}^{m} w_i (v_i - v(k_i))^2 \tag{2}
\]

After comparing mainstream fitting algorithms, the Levenberg-Me quart coupling general global optimization algorithm is selected. It can jump out of local optimal solution without giving proper initial values of parameters. The model results are shown in Figure 7(a)–(d), and Table 4 records the iteration results.

Table 4. Fitted results and model parameters of roads.

| Road | Correlation Coefficient | Root Mean Square Error | \( v_m \) (km/h) | \( v_f \) (km/h) | \( a \) |
|------|-------------------------|------------------------|-----------------|----------------|-----|
| SSM  | 0.77                    | 0.97                   | 17.48           | 13.8           | 5.56|
| XTL  | 0.91                    | 0.96                   | 17.16           | 12.54          | 5.39|
| SQL  | 0.891                   | 1.894                  | 24.19           | 21.44          | 7.41|
| XQL  | 0.848                   | 1.953                  | 19.52           | 18.75          | 7.99|

By comparing the similarities and differences between the results of roads inside and outside the campus, several points is found as follows. Since most of the non-motorized vehicle on campus are bicycles, the traffic flow basically forms a unity flow. The distribution span of the scatter diagrams is smaller, the width of the entire area is relatively balanced, and the randomness is weakened. \( v_m \) and \( v_f \)
outside the school are significantly higher than those inside the school, which proves that more electric bicycles can increase the free flow velocity. 3) The free flow velocity of XTL, SQL and XQL are close to the faster components of their binary speed distribution, which verifies that the components of speed distribution is divided by driving state.

5. Conclusion
This paper is a preliminary exploration of non-motorized vehicle traffic on campus. It introduces the basic traffic conditions of Tsinghua University, then chooses two typical roads for statistics. After that, non-motorized vehicle speed distribution model and speed-density model are established, and compared with external roads. Non-motorized vehicle, as the vital tool for transportation, should be given full attention to. Construction must adhere to the principle of combining short-term with long-term development, and meet need with the unification of the environment to ensure the safety of students. In the future expansion, adjustment, merging and new construction of universities, more research should focused on non-motorized vehicle transportation. Beginning from real demand, planning and design of transportation facilities, overall arrangements for organization, and construction of operating mechanism for management need to be devoted.

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