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Development of Driving Condition for Urban Bus Lines in Xi'an

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Abstract

The operating conditions of typical urban bus line in Xi'an are measured by GPS equipment with the sampling frequency at 1Hz. The transient driving condition is constructed by short stroke division and cluster analysis. According to the ECE-EUDC condition, a simplified model of modal driving condition is proposed. The model objective function and constraint condition are given according to the sampling data. And multi-objective optimization theory is used to develop modal driving condition. The errors between the developed driving conditions and sampling data show that the developed transient condition and modal condition can truly reflect the actual operation status of Xi'an city bus, which can provide the theoretical basis for vehicle control strategy optimization and parameter matching.

Key words: urban bus line; transient condition; modal condition; error analysis

1 Preface

The vehicle driving condition is a speed-time process that is used to describe vehicle driving characteristics in a particular traffic environment. It plays an important role in the field of automobile research, matching and testing. According to the form of division, driving conditions can be divided into transient condition and modal condition. The transient condition is the dynamic curve of the vehicle speed with time, which can reflect the dynamic characteristics of the road driving. But it is difficult to be used in the real vehicle bench test. The modal condition has a very simple shape, so it is easy to test the vehicle in test-bench and real-world^{[1]-[6]}. In this paper, the development of transient and modal driving condition for urban bus lines in Xi'an is discussed. The clustering analysis method is used to develop the transient condition. And multi-objective optimization theory is used to develop modal driving condition. The accuracy of both of driving condition is verified by the relative error of characteristic parameters between the driving conditions and the total sampling data. The results show that the developed transient condition and modal condition can truly reflect the actual operation of Xi'an city bus.

2 Construction of transient conditions

2.1 Data collection

The GPS acquisition equipment is installed in the urban and suburban buses. The sampling frequency of the on-board device is 1Hz. This paper has continuously collected 15 days' data, which has taken full account of many factors, such as operating time of city bus, city traffic flow, holiday, weather and so on. The cumulative mileage of the experiment reaches 2238km, totalling 544,700 effective speed information, which meets the requirements of the construction conditions.

2.2 Construction of transient conditions

Transient conditions are combined by a number of travel segments that vary dynamically over time. In this paper, short stroke and cluster analysis method are used to build transient conditions. The kinematic segments are divided into short stroke segments, which are the car travel process between two adjacent parking points, consisting of a parking section and a travel part. The urban and suburban sampling data are divided into 4839 representative fragments. For each representative fragment, 26 characteristic parameters were obtained. The principal component analysis and clustering analysis of feature parameters are carried out by using SPSS software. The motion segments are divided into three types of representative cases: congestion, general, smoothness. The weight of the three representative cases are determined according to the each type of short strokes number. According to the minimum principle of relative error between the segment and the total sample characteristic parameters, the representative fragments are sorted. And then driving conditions are synthesized according to the proportion of various categories. Xi'an transient driving conditions completed in accordance with the above method, as shown in Figure 1. Urban transient condition is named XAUB-TS. Suburban transient condition is named XASUB-TS. Table 1 are the characteristic parameters of urban line and suburban line transient conditions.

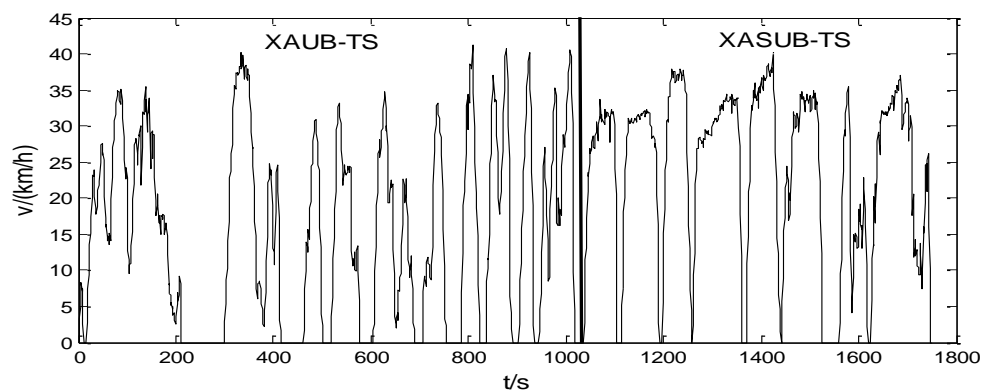


Figure1: Urban line and suburban line transient driving conditions of Xi'an city

Table 1: Comparison of parameters of Urban and Suburban Line Samples and Transient Conditions

Parameters	V_{max}	V_m	V_{mr}	V_{sd}	A_{max}	A_{mean}	D_{max}	D_{mean}	A_{sd}	P_{0-10}
XAUB-TS	41.26	14.83	20.60	12.88	1.55	0.52	-2.56	-0.66	0.53	0.15
Urban sample	50	15.22	20.86	13.09	2.98	0.52	-2.94	-0.63	0.51	0.15
XASUB-TS	40.12	23.94	26.79	11.92	1.74	0.54	-2.42	-0.67	0.55	0.07
Sub-sample	55	25.73	29.29	13.35	2.89	0.48	-2.89	-0.68	0.51	0.08

Parameters	P_{10-20}	P_{20-30}	P_{30-40}	P_{40-50}	P_{50-60}	P_{60-70}	P_a	P_d	P_c	P_i
XAUB-TS	0.19	0.22	0.15	0.01	0	0	0.32	0.25	0.14	0.28
Urban sample	0.18	0.23	0.16	0.01	0	0	0.31	0.25	0.17	0.27
XASUB-TS	0.14	0.22	0.47	0.01	0	0	0.30	0.25	0.34	0.11
Sub-sample	0.08	0.14	0.57	0.01	0.001	0	0.29	0.21	0.39	0.12

3 Construction of modal conditions

3.1 Model of modal conditions

The operating state of the vehicle on the actual road can usually be simplified to acceleration, deceleration, uniform and idling. With reference to the ECE-EUDC condition, the urban line modal condition is simplified to the model of Fig. 2, and the suburban line modal condition is simplified to the model of Fig. 3.

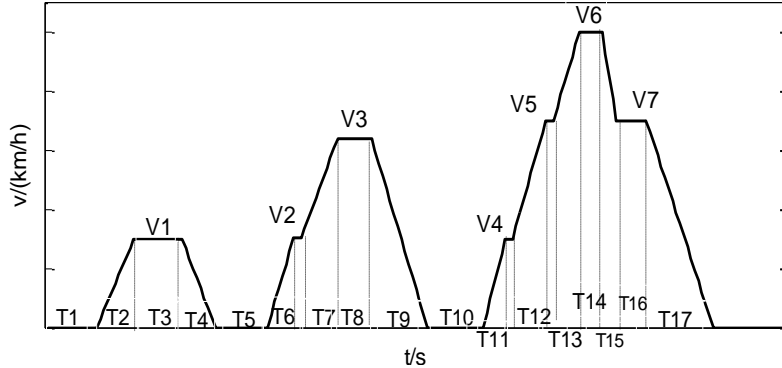


Figure2: The model of urban line modal conditions

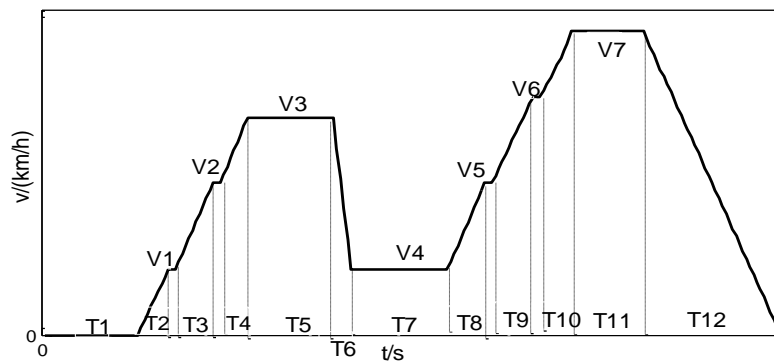


Figure3: The model of suburban line modal conditions

3.2 Analysis of modal conditions model

The model of modal condition need to optimize the running time and speed of each operation section. The optimization variables include 17 time variables and 7 speed variables. The multi-objective optimization theory is used to solve optimal solution of the model. The eight important statistical indicators are selected as the objective function optimization calculation, such as idling ratio F_{Pmi} , acceleration ratio F_{Pma} , constant speed ratio F_{Pmc} , deceleration ratio F_{Pmd} , average speed F_{Vm} , average running speed F_{Vmr} , average acceleration F_{Am} , average deceleration F_{Dm} . The objective function determination method is shown in formula (1) - (10).

$$F_{Pmi} = \left| \frac{(T_1 + T_5 + T_{10})/T - P_i}{P_i} \right| \quad (1)$$

$$F_{Pma} = \left| \frac{(T_2 + T_6 + T_7 + T_{11} + T_{12} + T_{13})/T - P_a}{P_a} \right| \quad (2)$$

$$F_{Pmc} = \left| \frac{(T_3 + T_7 + T_8 + T_{14} + T_{16} + 6)/T - P_c}{P_c} \right| \quad (3)$$

$$F_{Pmd} = \left| \frac{(T_4 + T_8 + T_9 + T_{15} + T_{17})/T - P_d}{P_d} \right| \quad (4)$$

$$F_{Vm} = \left| \frac{S/T - V_m}{V_m} \right| \quad (5)$$

$$F_{Vmr} = \left| \frac{S/(T - T_1 - T_5 - T_{10}) - V_{mr}}{V_{mr}} \right| \quad (6)$$

$$F_{Am} = \left| \frac{(V_1 + V_2 + V_6)/(3.6 \times (T_2 + T_6 + T_7 + T_{11} + T_{12} + T_{13})) - A_m}{A_m} \right| \quad (7)$$

$$F_{Dm} = \left| \frac{-(V_1 + V_2 + V_6)/(3.6 \times (T_4 + T_8 + T_9 + T_{15} + T_{17})) - D_m}{D_m} \right| \quad (8)$$

$$T = T_1 + T_2 + \dots + T_{17} \quad (9)$$

$$\min F = \sum_{i=1}^8 \omega_i F_i \quad (10)$$

In the above formula, S is the running distance, which is the graphic area in Fig. 2. F_i are eight statistically significant indicator. ω_i is the weight factor of the above eight sub-targets. P_i , P_a , P_c , P_d , V_m , V_{mr} , A_m , D_m are parameters of the sample data, which represent the idling speed, the acceleration ratio, the constant speed ratio, the deceleration ratio, the average speed, the average running speed, the average acceleration and the average deceleration.

According to the characteristic parameters of the sample data of urban line and the characteristic parameters of the transient condition, the maximum speed of the urban line mode is defined as 50km/h, the maximum acceleration and deceleration are not more than $3m/s^2$, and the up-shift points are 15km/h, 35km/h, 50km/h. The constraints of the model objective function are shown in formula (11).

$$\begin{aligned}
 & \left. \begin{aligned}
 & V_1 < 15 \\
 & V_3 < 35 \\
 & V_6 \leq 50 \\
 & 15 < V_2, V_4 \leq 20 \\
 & 35 < V_5 \leq 40 \\
 & V_1 / (3.6 \times T_2) < 3 \\
 & V_1 / (3.6 \times T_4) < 3 \\
 & V_2 / (3.6 \times T_6) < 3 \\
 & (V_3 - V_2) / T_7 < V_2 / T_6 \\
 & V_3 / (3.6 \times T_9) < 3 \\
 & V_4 / (3.6 \times T_{11}) < 3 \\
 & (V_6 - V_5) / T_{13} < (V_5 - V_4) / T_{12} < V_4 / T_{11} \\
 & (V_6 - V_7) / (3.6 \times T_{15}) < 3 \\
 & V_7 / (3.6 \times T_{17}) < 3
 \end{aligned} \right\} S.t. \quad (11)
 \end{aligned}$$

The construction principle of the objective function and the constraint condition of the suburb model is consistent with the urban model. According to the maximum speed of the sample and the relevant speed limit of the bus company, the maximum speed of the suburban line mode is defined as 55km/h.

3.3 Model optimal solution

This paper gives the eight important indexes weighted ω_i to transform the multi-objective into a single objective solution. For the above model target variables, the eight variables of the above objective function reflect the important characteristics of the vehicle driving conditions, and have parallel relations. Therefore, this paper defines eight indicators of equal weight, that is $\omega_i=0.125$.

The model is optimized based on the objective function and the constraint condition. The optimal solution of the various parameters are X1 and X2 through the use of computer programming, MATLAB optimization toolbox and time round calculation. The expression of optimizing solutions X1 and X2 are as follows: X1= (T₁, T₂... T₁₇, V₁, V₂... V₇). X2= (T₁, T₂... T₁₂, V₁, V₂... V₇).

X1=(16,11,9,9,16,8,11,6,15,16,7,10,8,4,4,6,18,14.96,15.182,34.631,15.065,35.1,50,34.936).

X2=(22,8,11,8,15,6,39,12,10,3,9,32,14.9,35.1,49,15,35.02,50.06,55).

According to the optimization results, the urban modal condition (named XAUB-MD) and suburban line modal condition (named XASUB-MD) are shown in Figure. 4-5, respectively. Their characteristic parameters are shown in Table 2.

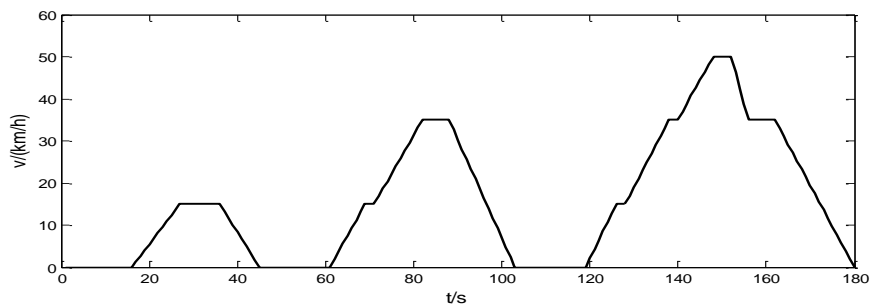


Figure4: Urban line modal condition

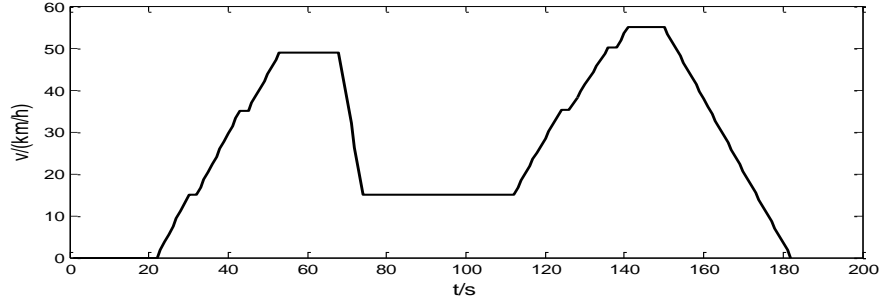


Figure5: Suburban line modal condition

Table 2: Comparison of modal conditions parameters

Parameters	V_{max}	V_m	V_{mr}	V_{sd}	A_{max}	A_{mean}	D_{max}	D_{mean}	A_{sd}	P_{0-10}
XAUB-MD	50	15.34	21.41	14.85	0.60	0.51	-1.04	-0.60	0.42	0.17
XASUB-MD	55	25.82	29.56	13.66	0.52	0.48	-1.58	-0.65	0.52	0.05
Parameters	P_{10-20}	P_{20-30}	P_{30-40}	P_{40-50}	P_{50-60}	P_{60-70}	P_a	P_d	P_c	P_i
XAUB-MD	0.22	0.11	0.16	0.07	0	0	0.31	0.26	0.16	0.28
XASUB-MD	0.30	0.11	0.13	0.19	0.09	0.00	0.29	0.21	0.38	0.13

4 Verification of driving conditions

4.1 Transient condition verification

Ten typical and statistically significant characteristic parameters of V_{mean} , V_{mr} , V_{sd} , A_{mean} , D_{mean} , A_{sd} , P_a , P_d , P_c and P_i were selected as the error evaluation criteria to evaluate the driving conditions constructed above [6]. The error and average error are calculated as shown in formula (12) (13), and the error calculation results are shown in Table 3.

$$\delta_i = \frac{|A_i - A|}{A} \times 100\% \quad (12)$$

$$\bar{\delta} = \frac{1}{n} \sum_{i=1}^n \delta_i \quad (13)$$

Where δ_i is the error of each eigenvalue index, $\bar{\delta}$ is the average error of driving condition, A is the characteristic value of the sample data and A_i is the characteristic value of the construction condition.

Table 3: Relative error analysis between transient condition and total sample data

Error (%)	$\delta_{V_{mean}}$	$\delta_{V_{mr}}$	$\delta_{V_{sd}}$	$\delta_{A_{mean}}$	$\delta_{D_{mean}}$	$\delta_{A_{sd}}$
XAUB-TS	2.579	1.274	1.576	0.917	5.571	2.997
XASUB-TS	6.954	8.554	10.692	13.53	1.722	7.74
Error (%)	δ_{P_a}	δ_{P_d}	δ_{P_c}	δ_{P_i}	δ	$\bar{\delta}$
XAUB-TS	4.968	0.036	14.683	3.563	38.165	3.816
XASUB-TS	6.113	18.687	10.573	12.653	97.217	9.722

As shown in Table 3, the average errors between the transient condition constructed by this paper and sample data are less than 10%. Thus the transient condition can reflect the actual driving characteristics of Xi'an buses in urban and suburban areas.

4.2 Modal condition verification

As the transient condition and modal condition are used to describe the actual operation of the vehicle road, the modal conditions can be verified from two factors: transient verification and sample verification. The error analysis results of modal and transient conditions are shown in Table 4. The average error of the urban modal and transient conditions is only 7.33%. The average error of the suburban modal and transient conditions is about 10%. Therefore, the modal condition can accurately reflect the characteristics of transient conditions.

The results of the modal and total sample error analysis are shown in Table 5. The average error between the urban modal and the sample data is 5.45% and the average error between the suburban modal and the sample data is only 1.77%. Thus the modal condition can reflect the actual driving state of the vehicle, and the construction method of modal condition is certain scientific and accuracy.

Table 4: Relative error analysis between modal condition and transient condition

Error (%)	δ_{Vmean}	δ_{Vmr}	δ_{Vsd}	δ_{Amean}	δ_{Dmean}	δ_{Asd}
XAUB-MD	3.362	3.784	13.285	3.767	10.116	24.589
XASUB-MD	7.27	9.37	12.73	13.97	2.94	5.01
Error (%)	δ_{Pa}	δ_{Pd}	δ_{Pc}	δ_{Pi}	δ	$\bar{\delta}$
XAUB-MD	5.296	0.567	7.453	1.108	73.329	7.333
XASUB-MD	6.08	17.73	9.01	16.01	100.10	10.01

Table 5: Relative error analysis between modal condition and total sample data

Error (%)	δ_{Vmean}	δ_{Vmr}	δ_{Vsd}	δ_{Amean}	δ_{Dmean}	δ_{Asd}
XAUB-MD	0.81	2.608	13.503	2.747	4.127	17.331
XASUB-MD	0.34	0.90	2.34	0.39	4.53	2.60
Error (%)	δ_{Pa}	δ_{Pd}	δ_{Pc}	δ_{Pi}	δ	$\bar{\delta}$
XAUB-MD	0.312	0.534	7.812	4.724	54.507	5.451
XASUB-MD	0.03	0.81	1.72	3.99	17.65	1.77

5 Conclusion

This paper mainly explores the construction method of transient condition and modal condition. The actual operation data of city bus are collected by GPS equipment. The clustering analysis method is used to construct the transient condition of Xi'an bus line. The model of modal conditions are established according to the ECE-EUDC condition. The objective function and the constraint condition are determined based on the characteristic parameters of the total sample data. The weighting factor is used to convert the multi-objective into a single-objective. Then the

construction of modal condition are completed according to the optimal solution. The accuracy of the driving condition is verified by the relative error of characteristic parameters between the driving condition and the total sample data. The average errors between the driving condition and the total sample data are less than 10%. The results show that transient condition and modal condition in urban and suburban areas can truly reflect the actual operation of the vehicle, which provide theoretical basis for vehicle control strategy optimization and parameter matching.

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