Various Scenario Driving Cycle Construction Method Based on Speed Ranges

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Abstract. In order to meet industry needs of self-development of driving cycles that can represent various road scenarios, this paper proposes a construction method and tool to construct driving cycle based on speed ranges: Collect, segment and clean real road speed data to establish segment database representative of scenario characteristics; Divide database into speed range to define various driving situation ; Specify phase duration and structure design rules to define cycle phases containing a specified number of segments; Standard select and combine segments to construct phase cycles; Randomly combine and verify phase cycles to stably and automatically construct the output driving cycles.

Keywords: Driving cycle, Various road scenario, Self-development tool.

1 Introduction

Reference driving cycles describing speed versus time curves which serve as input for bench test is the basis for vehicle performance evaluation emission legislation and control development. Various road scenarios distinguished by factors such as vehicle type, purpose, driving area, and style, etc possesses diverse driving characteristics[1]. For industries focusing on vehicle performance under specific scenario, it is necessary to have a construction method provides for cycle self-development: Based on real-road collected speed data , various driving scenarios are defined and distinguished by database characteristic features to output a driving cycle representing driving characteristics of scenarios.

A series of studies on the construction methods of driving cycles have be proposed: Jiang et al. divided a series of driving cycles into different clusters by factor analysis to get driving cycles for different clusters of typical roads in Hefei[2]; Qin Datong et al. proposed a method for constructing urban cycle conditions based on K-means clustering algorithm [3]. Ge et al proposes a method of constructing a car driving situation based on the minimum error analysis, used comprehensive parameter value (CPV) to evaluate the rationality of the curve[4];The above studies have achieved certain results, but their construction process are relatively complex and uncontrolla-

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ble, requiring follow-up, judgment, and adjustment based on profound knowledge and experience in fields of data analysis and cycle construction.

To address the issue above, this paper proposes a construction method of driving cycle based on speed ranges: Segment database is established by processing and analyzing real-road data collected under specific scenarios; Database are classified into speed ranges to define various driving status; Cycle phases containing a specific number of segments are defined based on specified cycle duration and structure design rules; Phase curves are constructed by standardized segment selection and combination; Curves are randomly combined across phases and verified with collected database to construct the output driving cycle. The overall construction process is stable and controllable, as shown in figure 1.

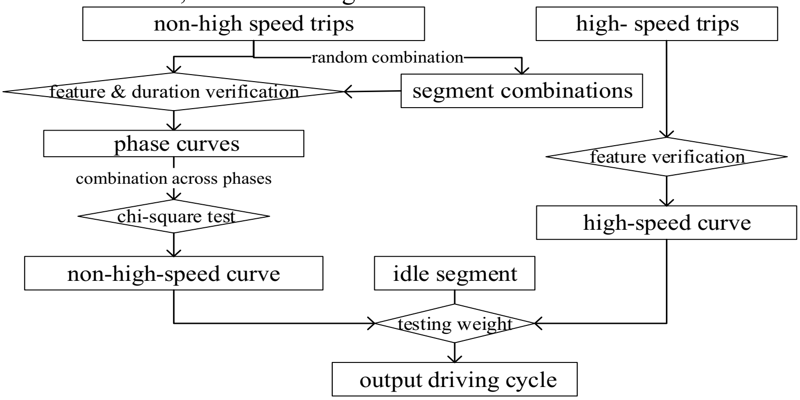


Fig. 1. Construction process of driving cycle base on speed ranges

A cycle construction tool was developed in Matlab to generate cycles by instant and convenient interface operation, thus, meeting the self-development need of industry[5-6]. This paper presents overall process of construction based on collected real-road data and interface operation.

2 Data Processing

2.1 Short Trips Cutting and Selecting

This paper collected real-road free-driving speed data from 15 heavy-duty vehicle fleet of 12 months, with frequency of 1Hz and distance of 57,000 km. Fleet's driving routes covered various scenarios.

Driving cycles are to be constructed by combining movements cut out from this database. In this paper, movements from one start to the next stop is cut out to form 68159 short trips, while next movement from one stop to next start is cut out as corresponding idle segment.

Influence of uncontrollable factors can lead to invalid data collection. Therefore, trip cleaning rules are denoted:25620 trips with maximum speed v_{max} in range of (5,130km/h), maximum acceleration a_{max} below 4.5m/s^2, minimum deceleration a_{min}

above -4.5m/s^2, duration in range of (5,3600s), corresponding idle segment duration below 200s are selected available trip database.

6 feature parameters of available trips are calculated, including: average speed (km/h), Con duration (seconds with acceleration between -0.1~0.1 m/s^2), Acc duration (seconds with acceleration above 0.1m/s^2), average Acc (average value of acceleration duration), Dec duration (seconds with acceleration value below -0.1m/s^2), and average Dec (average acceleration value of deceleration duration).

2.2 Speed Range Classification

To distinguish among driving scenarios under which vehicles are operated in various speed ranges, short trips are classified and analyzed to generate driving cycle effectively reflecting time distribution of various scenarios and their corresponding real-road driving situation[7].

Trips with average speed in range of (i×5,(i+1)×5km/h) (i=0,1,2... 20) and corresponding idle segments are classified into the i^{th} speed range database. Based on feature parameters of N_i trips in the i^{th} database, Its overall features are obtained, as shown in table 1:

Table 1. Features of speed ranges

Range (km/h)	Average Speed	Average Acc	Average Dec	Trip number	Average duration(s)	Total duration	Duration ratio(%)
0~5	3.91	0.29	-0.27	5851	23.24	135977	3.1
……							
80~85	81.57	0.19	-0.21	13	2196.85	28559	0.65
85~90	85.52	0.24	-0.28	2	1140.5	2281	0.05
Idle						1169656	26.63

3 Phase Curve Structure Designation

Structure of output cycle is designed based on speed range features: Firstly, duration ratio of trips in each speed range and total idle segments are calculated to obtain cycle duration for each speed range and idle range; Next, initial number of trips contained in each range curve is estimated based on average trip duration; Lastly, output driving cycle duration is self-defined based on results above. Process of cycle structure designation is shown in figure 2:

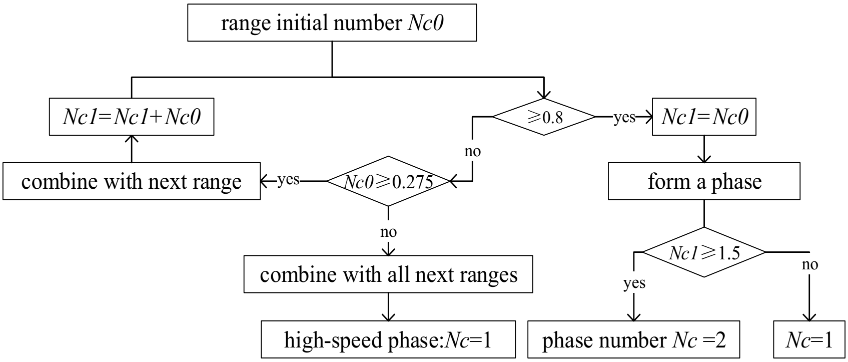


Fig. 2. Design process of cycle structure

3.1 Range Duration and Initial Trip Number Determination

Firstly, total duration of the output driving cycle is initially self-defined as *LC*(s). Total duration of the trips Lv_i(s) in each speed range and all idle segments *Idlet*(s) are calculated to obtain cycle duration lv_i (s) of each range and idle cycle duration $Idlec$(s) based on its proportion[8]. as shown in equation 1 and 2:

$$lv_i = {LC \times Lv_i}/{(Idlet + \sum_{i=1...20} Lv_i)} \tag{1}$$

$$Idlec = {LC \times Idlet}/{(Idlet + \sum_{i=1...20} L_i)} \tag{2}$$

For i_{th} speed range database, divide lv_i by average duration value of short trips $L0_i$ to obtain initial number of trips, N_0 that should be contained in corresponding i_{th} range cycle. Furthermore, initial *LC* is adjusted to ensure that N_0 of each range is below 2.5, aimed to limit the final number of trips to value of 1 or 2.Final output *LC* is defined as 1800s in this paper.

Designing process above is automatically operated by construction tool. Result is presented on the interface, as shown in figure 3:

	TotalNum	AveDur $L0_i$	lvi Rat(%)	CycDur lv_i	IniNum $N0_i$
0~5	5851	23.24	3.10	55.73	2.40
5~10	5631	37.18	4.77	85.79	2.31
10~15	3815	64.95	5.64	101.54	1.56
15~20	2158	82.60	4.06	73.05	0.88
20~25	1782	114.34	4.64	83.49	0.73
25~30	1969	139.23	6.24	112.35	0.81
30~35	1602	181.96	6.64	119.45	0.66
35~40	1100	270.58	6.78	121.97	0.45
40~45	614	428.56	5.99	107.83	0.25

45~50	417	730.27	6.93	124.79	0.17
50~55	256	964.03	5.62	101.13	0.10
55~60	183	1162.06	4.84	87.15	0.07
60~65	97	1296.32	2.86	51.53	0.04
65~70	59	1456.92	1.96	35.23	0.02
70~75	51	1378.33	1.60	28.81	0.02
75~80	20	2220.80	1.01	18.20	0.01
80~85	13	2196.85	0.65	11.70	0.01
85~90	2	1140.50	0.05	0.93	0.00
90~95	0	0.00	0.00	0.00	NaN
95~100	0	0.00	0.00	0.00	NaN
100~105	0	0.00	0.00	0.00	NaN
Idle	0	1169656.00	26.63	479.32	0.00

Fig. 3. Range cycle design result

3.2 Range Combination

The following trip combination process assumes relatively high complexity and resource consumption, which is likely to fail self-development requirement. To address the issue, this paper denoted range combination rules for cycle designation in advance.

Rules are aimed to assure that: Nc_j of each combined phase is limited to value of 1 or 2, while complies with corresponding summed up N_0. Thus, following trip (combination) selection process can be standardized to direct feature verification or verification after a single random combination. Combination rules are as follows:

From low to high,successively determine whether to combine adjacent speed ranges based on N_0 : if $0.8 \leq N_0 \leq 1.5$, define current range as a new phase with Nc_j=1; If $1.5<N_0\leq 2.5$, define it as a new phase with Nc_j=2; If $0.275 \leq N_0<0.8$, combine it with next range successively until summed up N_0 is above 0.8, define the combined ranges as a new phase with Nc_j=1 ; If $N_0<0.275$, Combine it with all ranges left an define the combination high-speed phase (j=K), with Nc_K =1.

Process of speed range combination is shown in figure 4:

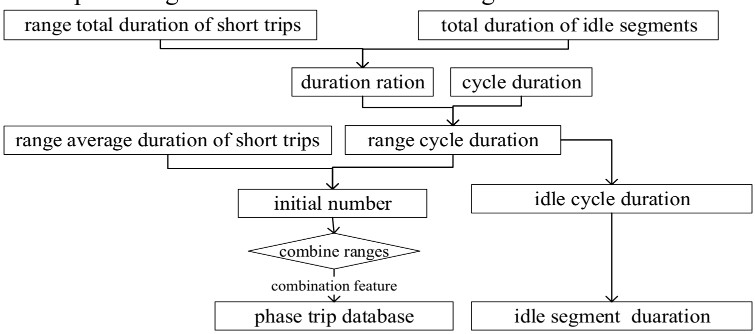


Fig. 4. Combination process of speed range

In this paper, range of 20~30, 30~45km/h are combined according to rules,thus, 6 non-high-speed phases are formed. Ranges above 45km/h are combined to form the high-speed range. Features of each phase are calculated based on its combined trip databases, as shown in figure 5.

	TotalNum	AveDur $L0_i$	lvi Rat(%)	CycDur lv_i	IniNum $N0_j$	PhaNum NC_j
0~5	5851	23.24	3.10	55.73	2.40	2
5~10	5631	37.18	4.77	85.79	2.31	2
10~15	3815	64.95	5.64	101.54	1.56	2
15~20	2158	82.60	4.06	73.05	0.88	1
20~30	3751	127.41	10.88	195.84	1.54	2
30~45	3316	257.02	19.41	349.25	1.36	1
45~105	1098	1021.15	25.52	459.47	0.45	1
Idle	0	1169656.00	26.63	479.32	0.00	12

Fig. 5. Speed range combination result

4 Driving Cycle Construction

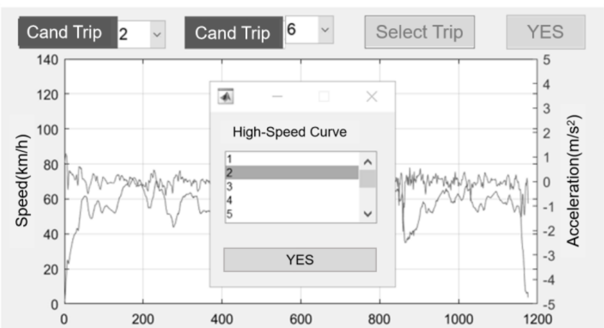
4.1 High-speed Cycle Construction

High-speed phase contains speed range of 45~105km/h. Most trips in this range represent driving scenarios on expressways or highways, where the vehicle are driven constantly as a long trip. The cycle duration allocated to high-speed phase in structure designation generally cannot contain such a long trip. Thus, this paper proposes to dismiss duration requirement while constructing high-speed curve. Time distribution situation between high-speed and non-high-speed scenarios can be reflected by test weights in following.

In order to ensure that output high-speed phase curve can effectively reflect real-road driving scenario, trip highly complies with phase database in terms of feature characteristics is selected as high-speed curve: Dimensionless distance D (%) between the 6 feature parameters of trip and database is calculated, as shown in equation 3:

$$D = \sum_{i=1,2\ldots 6} \frac{abs(\text{Trip feature}_i - \text{Database feature}_i)}{\sigma(\text{feature}i\text{ of all trips in database})} \tag{3}$$

Speed curve and feature verification result of candidate trips with min D are automatically presented for selection, as shown in figure 6. In this paper, trip 2 of 1176s was selected.



Database Feature	Ave Speed	Ave Acc	Ave Dec	Deviation	Duration
	57.41	0.25	-0.29	0.00	459
Deviation1	0.83	0.39	0.86	0.69	1219
Deviation2	0.45	0.12	0.90	0.49	1176
Deviation3	0.33	1.09	2.69	1.37	1524
Deviation4	2.04	1.01	2.78	1.95	814
Deviation5	1.55	2.79	1.30	1.88	1546

Fig. 6. High speed curve selection

Divide the total duration of idle segments by the total duration of all segments in high-speed database to obtain high-speed idle ratio $Idle_h$; Thus, duration of idle segment $Idlet_h$ contained in phase curve is calculated in equation 4:

$$Idlet_h = lc_h /(1-Idle_h) * Idle_h \tag{4}$$

Idle segment of 57s is added to selected trip to output the final high-speed phase cycle. Deviation between key feature parameters of cycle and collected database are all below 8%, as shown in table 2. Thus, high-speed driving scenario of heavy-duty vehicles in Guangzhou is nicely represented by the cycle:

Table 2. Feature parameters of high-speed curve

	Idle ratio	Average speed	Acc ratio	Dec ratio	Con ratio	Average acc	Average dec
Cycle	3.45	57.67	26.68	22.99	46.88	0.24	-0.30
Database	3.71	57.41	25.05	21.70	49.55	0.25	-0.29
Deviation	7.06	0.45	6.53	5.96	5.38	2.43	2.17

4.2 Non-high-speed Cycle Construction

Non-high-speed of (0~45km/) cycle is constructed based on structure designation result: For 15~20 and 30~45 phases with $Nc_j = 1$; Trip with D below 8% and duration within 5% deviation of phase cycle duration are selected as candidate curve. For other 4 phases with $Nc_j =2$, N_j trips are paired overall to form ($N_j*(N_j-1)/2$) combinations; Combination with available D and duration are selected as candidate curve.

Candidate curves are randomly selected and combined across phases to form several non-high-speed curves. A chi-square test comparing unified speed-acceleration distribution of curves and that of phase database is applied [9]. As a result, curve with the min chi-square confidential value of 95.89% is selected. 10 trips contained in the cycle are lined up from low to high in terms of speed, and idle segments of 42s are added between them to output non-high-speed driving cycle.

Deviation between key feature parameters of cycle and collected database are all below 8%, as shown in table 3. Thus, non-high-speed driving scenario of heavy-duty vehicles in Guangzhou is nicely represented by this cycle.

Table 3. Feature parameters non-high-speed curve

	Idle ratio	Average speed	Acc ratio	Dec ratio	Con ratio	Average acc	Average dec
Cycle	34.92	24.16	23.51	21.62	19.95	0.32	-0.36
Database	34.90	24.87	22.27	21.27	21.56	0.34	-0.39
Deviation	0.07	2.85	5.54	1.64	7.45	5.98	7.02

4.3 Driving Cycle Application

The final output driving cycle consists of high-speed cycle of 1233s and a non high-speed cycles of 1323s, as shown in figure 7:

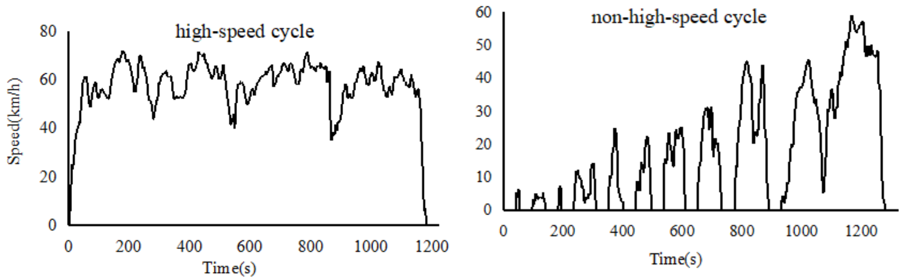


Fig. 7. Output driving cycle

2 Cycles are to be applied respectively on test-bench for vehicle performance test. [10]. To reflect real-road time distribution between high-speed and non-high-speed scenarios, testing weight is assigned to high-speed cycle as W_H =28.06%, and non-high-speed cycle as W_{NH} =71.94%. Weight calculation is shown in equation 5:

$$\frac{\text{high speed cycle duration}\times W_H}{\text{non}-\text{high speed duration}\times W_{NH}} = \frac{\text{total segment duarion in high speed database}}{\text{total segment duarition in non}-\text{high speed database}} \quad (5)$$

Test results of 2 cycles are weighted to output the final result nicely representing various real-road driving scenario of heavy-duty vehicles in Guangzhou.

5 Conclusions

In this paper, driving cycle structure is designed base on characteristic analysis of real-road database classified by various speed range to nicely effectively reflect time distribution of various scenarios, and real- road driving situation of specific scenario.

In this paper, reasonable range combination methodology is proposed to control the random trip selection. Based on this, abstract database features are translated into intuitive results of cycle duration and trip numbers, thus, meeting self-development need of industry.

In this paper, based on the real-road database collected under specific scenarios, feature characteristic verification and chi square test are applied to assure that output driving cycle can nicely represent various driving situation.

In summary, by applying driving cycle constructed by method and tool proposed in this paper on test-bench, vehicle performance evaluation under various scenarios can be nicely achieved.

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