SOCIETY OF AUTOMOTIVE ENGINEERS, INC.
Two Pennsylvania Plaza, New York, N.Y. 10001

Development of the Federal Urban Driving Schedule

Ronald E. Kruse and Thomas A. Huls
Environmental Protection Agency

SOCIETY OF AUTOMOTIVE ENGINEERS

Automobile Engineering Meeting
Detroit, Mich.
May 14–18, 1973

730553

730553

Development of the Federal Urban Driving Schedule

Ronald E. Kruse and Thomas A. Huls
Environmental Protection Agency

MOTOR VEHICLE EXHAUST is a complex mixture of nitrogen (N), carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), hydrocarbons (HC), oxides of nitrogen (NO_x), and other materials. The concentration of these exhaust components is variable and dependent upon the vehicle's operating mode. The measurement of the gaseous pollutants from motor vehicles, usually CO, HC, and NO_x, requires the use of sophisticated, complicated, and delicate instrumentation. It is extremely difficult to use this instrumentation in conjunction with motor vehicles as they are being operated in the urban traffic environment A motor vehicle can be operated in a laboratory on a chassis dynamometer and exhaust emissions can be properly measured. Basic questions which must be answered when vehicle emissions are measured in the laboratory are, how is the vehicle to be operated and how does one decide upon the driving conditions which will be represented by this operation? These are questions which are most difficult to answer (1)*. Many groups have over the years, conducted research projects which have added to the understanding of motor vehicle traffic-related, operating characteristics.

*Numbers in parentheses designate References at end of paper.

HISTORY

Among the early contributors to this understanding of urban traffic characteristics were personnel of the Los Angeles County Air Pollution Control District. They worked in cooperation with, or considered the work of, other groups in their efforts to identify driving habits or vehicle operating characteristics which typify Los Angeles traffic.

In the late 1950s, Los Angeles County personnel in association with members of the Automobile Manufacturer's Association Traffic Survey Panel identified 11 characteristic driving modes which could be used in combination with appropriate weighting factors to characterize Los Angeles driving. This work culminated in the development of the California 7-mode cycle. The 7-mode cycle was based on the 1956 (2) survey and was intended to represent average driving conditions throughout Los Angeles County during both peak and off-peak traffic conditions

Early in the 1960s, the California air pollution personnel re-evaluated their criteria for determining average driving

ABSTRACT

This paper reviews the development of the LA 4 road route, and discusses efforts directed toward development of a short repetitive dynamometer cycle based upon the road route Also described are the instrumentation, methods, and selection process used to obtain a speed profile of a typical drive over the 12 mile long route The methods used to shorten the speed profile to 7.5 miles, and to shorten the average trip length, while preserving trip description such as average speed, idle time, number of stops, etc., are explained. A measure of the correlation of emissions from vehicles driven over the EPA Urban Dynamometer Driving Schedule (UDDS) and over the full LA 4 driving schedule is provided

The UDDS is a speed-trace consisting of 18 profiles. separated by idle periods of 0-39 s duration The schedule covers 7 46 miles in 1372 s for an average speed of 19.6 mph.

conditions and decided that the cycle should not represent 24 h county-wide vehicle operation They felt that it was necessary to concentrate on the kind of driving which contributes to the peak primary pollutant levels in the Los Angeles basin (3).

They determined that the largest contributor to Los Angeles smog was the morning home-to-work trip. They felt that if they could identify the prevalent operating modes, they could reproduce those modes with vehicles on chassis dynamometers and measure exhaust emissions which result from these modes. As a part of their efforts, they instrumented several automobiles with the Du Pont driving habits recorder which recorded time in each driving mode. This device determined the amount of time spent in each of the 16 to 19 engine speed-manifold pressure categories. The data were displayed on elapsed time clocks, one clock for each mode, with one additional clock to measure total elapsed time This was the state-of-the-art in the early 1960s (3). The Engineering Research & Development (ER&D) Section of the Division of Air Pollution of Health, Education and Welfare (HEW), the predecessor to the Office of Mobile Source Air Pollution Control (OMSAPC) of the Environmental Protection Agency (EPA), built a modified version of the Du Pont driving habits recorder in the early 1960s. This recorder functioned in the same way as the Du Pont recorder, except that it had 36 engine speed-manifold pressure categories. Evaluation of the HEW driving habits recorder indicated that the data gathered by that device were difficient in the basic respect that the chronology of the mode events was lost. Subsequently, a 22 channel strip chart event recorder was used to collect the same type of data. While this approach allowed analysis of the chronology of each trip, the data reduction problem was formidable. The next step was to use a fifth wheel and tachometer-generator, attached to the back of the car, combined with a potentiometric strip chart recorder. While this approach provided a good visual display of a trip, it also suffered data reduction problems, as had been noted by others (2).

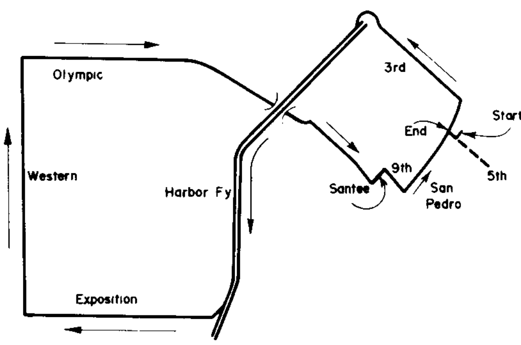
Attempts were made to reduce the strip chart speed recordings to key punch cards, but even with the use of mechanical curve readers this method was impractical. While this method of recording data provided useful and interesting information about road routes as they were driven, it could not be used, at this stage of development, to determine typical or representative routes. Because of these data reduction problems, the project was set aside at this point of development, in 1963.

REPRESENTATIVE ROAD ROUTES

Meanwhile, Los Angeles County and California personnel were gathering traffic and driving habits data, evaluating the data, and finding street segments which represent various driving habit patterns (3). Having classified many of the urban Los Angeles street segments by driving type, they undertook to develop a continuous road route which contained segments such that the total route represented the Los Angeles morning trip to work. This was a tremedous task and involved developing and discarding many routes before the Los Angeles road route designated LA 4 was decided upon (Fig. 1). HEW participated in the latter stages of this development by providing technical staff and equipment for proportional exhaust sampling over the route (February 1966).

In September 1966, HEW personnel used the PHS-Ethyl driving modes analyzer (4) to develop driving mode data from the LA 4 road route These data were analyzed and a similar route (CLA 4) was constructed in Cincinnati, Ohio. This route was the local basis for comparison with cycles being developed for replacement of the 7-mode cycle for certification testing. The candidate cycles were compared to the CLA 4 route by both proportional sampler emission tests and by driving modes analyzer tests To produce a driving cycle which met both the emission and the driving mode criteria, and which was of the same general format as the 7-mode cycle, was a very difficult and time-consuming task This work was conducted through the summer of 1968, and the most likely short cycles were carefully compared to the CLA 4 road route.

In August 1968, a large part of the mobile source activity was moved from Fairfax, Ohio, to Ypsilanti, Mich., in



1 Start behind Country Air Pollution Laboratory.
2 Right on Fifth
3 Right on San Pedro.
4 Left on Third St.
5 Up ramp to Harbor Fy. South.
6 Exit Harbor Fy. at Exposition.
7 Follow Exposition to Western
8 Right on Western.
9 Right on Olympic
10 Left on Santee.
11 Right on Ninth.
12 Left on San Pedro
13 End just beyond intersection

anticipation of the construction of a new mobile source emissions laboratory in Ann Arbor. This move disrupted most of the mobile sources research and development activities. While some cycle development activities continued at the Fairfax facilities, the Procedures Development Branch personnel at Ypsilanti began to contribute as much as possible to the project.

The equipment available during the transition included an automobile, a fifth wheel with tachometer-generator, a strip chart recorder, and a d-c to a-c inverter. The combination of these items allowed the recording of actual road speed during trips on the road. Since it was known that the Fairfax facility would ultimately be closed and that the CLA 4 would become inaccessible, it was decided to investigate the possibility of developing an Ypsilanti version of the CLA 4, which was to be termed YCLA 4. It was realized, of course, that the genuine LA 4 route in downtown Los Angeles was the standard route, but it was felt that the experience which was acquired during the development of the YCLA 4 would aid the analysis of LA 4 data and the development of a representative cycle.

Engineers working on the project drove over several roads and streets in the Ypsilanti area and recorded route speed profiles with the same basic equipment that had been used five and more years earlier. They struggled with the same data reduction problems as before to get useful mode data from the long speed profile chart. It was noted, as was noted earlier, that the speed profile chart, taken in its entirety, was an excellent description of the trip. If an average trip could be driven over the route, then the speed profile chart would display all of the useful characteristics of the route.

TRANSFER OF SPEED PROFILE CHART TO DYNAMOMETER DRIVING

Once it was realized that the average speed profile chart contained not just the major modes of the route but also included all of the little mode changes which characterize real driving, consideration was given to how this information might be transformed to dynamometer driving. Of course, the simplest, and most straightforward method would be to use the route speed profile chart as a driving aid and drive the car to match its speed to the previously recorded speed profile. This was tried and it was found that a driver could indeed follow the speed profile with reasonable precision and without greater difficulty or more fatigue than was associated with driving an equivalent number of 7-mode cycles

The next step was to obtain a good speed profile of a typical drive over the LA 4 road route To accomplish this task, an engineer and an electronics technician were sent to Los Angeles with an instrumented car. The car used was a 1969 2-door Chevrolet with a 327 CID engine and 2-V carburetor. It had a gvw of 4000 lb. The instrumentation consisted of a 4-channel tape recorder, a fifth wheel with tachometer-generator. Coast Laboratory and laboratory personnel were used as drivers. Six different drivers were used. Two of the drivers drove the route twice each because of equipment malfunctions during their first drives. The six complete tapes were brought back to Ypsilanti and used to generate strip chart recordings for visual comparison. In addition, idle time, average route speed, maximum speed, and number of stops per trip were calculated, and the average was determined for each measurement. The total running time of the drives averaged 37.6 min, with a range of 35.3-40.0 min. The actual time spent driving (eliminating idle periods) averaged 31 min with a range of 29.8-32.4 min. One of the six good traces exhibited obviously excessive throttle movement. The remaining five traces had remarkably similar traces. Since the five traces were so similar, the drive with the actual driving time closest to the average of the six runs was selected as the basis for the driving schedule. This trip (trip 2 of Table 1) is represented pictorially in Fig. 2 which is a reproduction of the chart recording made from the original tape. This recording runs from right to left and from top to bottom. The beginning of the trip is at the upper right and the end of the trip is at the lower left. The speed trace is in the lower portion of the chart. The manifold pressure recording is located in the upper portion of the chart. The actual driving time for this drive was 31.2 min and the total running time was 37.7 min. (See Table 1.)

The LA 4 route is 12.0 miles long, which is longer than the average trip length, 7.5 miles (5), so a short version of the LA 4 recording was needed. Several weeks were spent deciding how the route could be shortened with the least amount of tampering. The LA 4 speed profile chart consists of a series of individual speed profiles connected by various length idle periods (Fig. 2). For identification purposes, these profiles were lettered A-Z plus AA and BB; H was further divided into Ha and Hb. The characteristics–top speed, average speed, elapsed time, and distance–were calculated for each of the profiles and then the like profiles were grouped together. (See Table 2.) It was decided that, where groups of like profiles existed, one complete profile of every three would be deleted. Fig. 3 presents one example of like profiles. Profiles G, Ha, and E are compared, and profile Ha was deleted from the LA 4 short route. The freeway portion of the route con-

Table 1 - Results of LA-4 Trip Recordings

Trip	Trip Time, min	Idle Time, min	Stops, number	Idle Time, %	Average Speed, mph*
2	37.10(3)**	6.79(3)	28(4)	18.30(3)	19.17(4)
4	35.67(1)	5.77(1)	28(4)	16.35(2)	19.94(6)
5	36.65(2)	5.83(2)	30(6)	15.90(1)	19.41(5)
6	38.00(4)	7.24(4)	27(2)	19.05(4)	18.72(3)
7	38.25(5)	7.84(6)	26(1)	20.50(6)	18.60(2)
8	40.32(6)	7.75(5)	28(4)	19.23(5)	17.64(1)
	37.67	6.87	27.8	18.22	18.91

*Based on 11 844 miles rather than 12.00 miles.

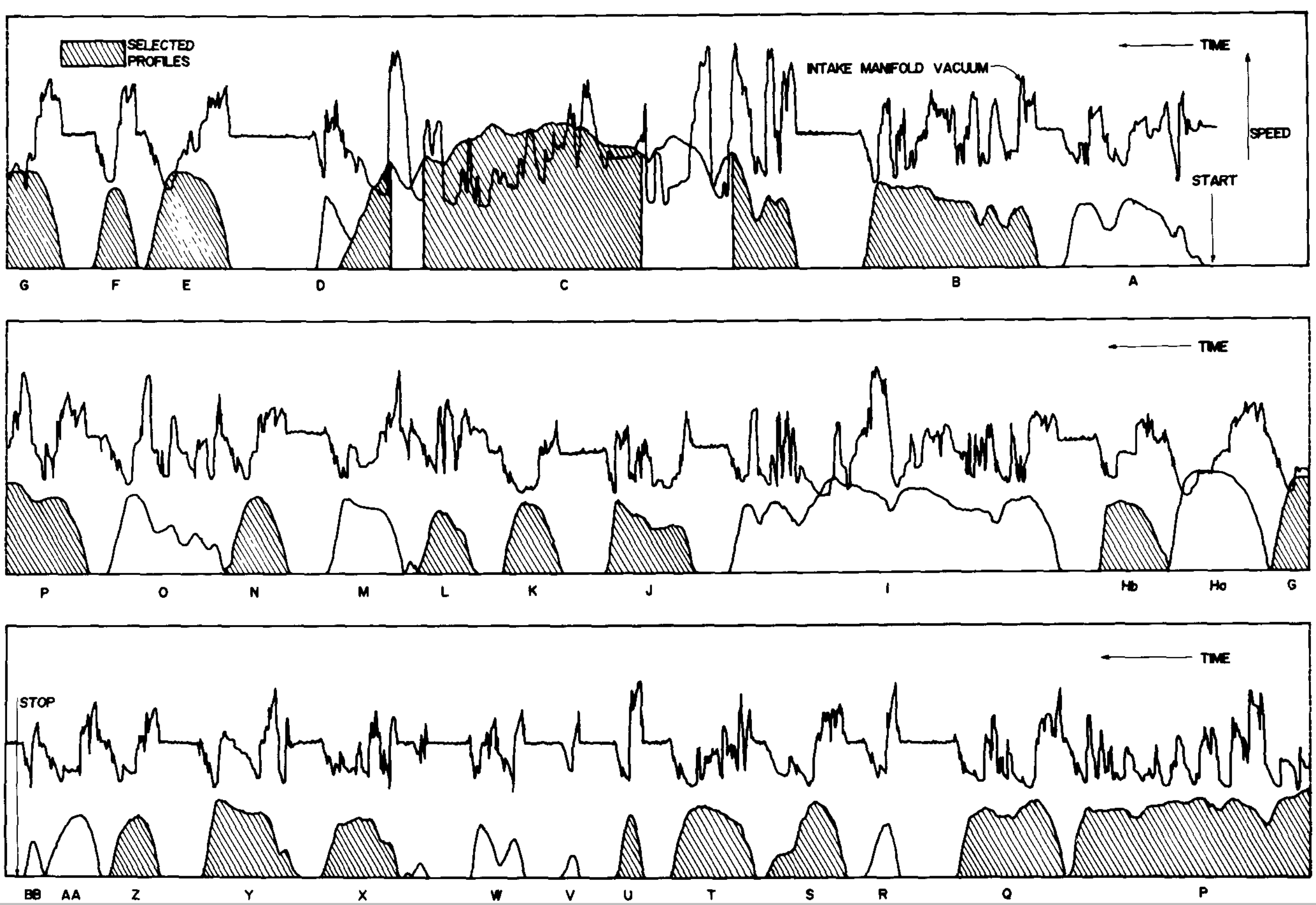
sisted of one long profile. About one-third of this profile was deleted. 1.125 miles were removed out of 3.065 miles of operation (96.7 s out of 263.5 s) in such a way that the original average speed of the profile was maintained. Fig. 4 shows the changes which were made to the original freeway profile. After each trial selection of profiles, the short schedule parameters, such as average speed, were calculated and compared to the parameters for complete route. Several different combinations of profiles were tried before the combination which was to become the short version of the LA 4 route was found. To aid in the selection of profiles for the shortened route, the actual number of idle periods was compared to the average of all of the road runs multiplied by the ratio of short segment distance to the total route distance. The expected number of idle periods was 17.6. The actual number of idle periods used in the shortened route, including an initial idle, was 18. It was also necessary to know how to apportion the 248 s of idle time among the 18 idle periods. A total of 167 idle periods were recorded during all of the trips. These idle periods were ranked according to duration, divided into 18 groups, and the average duration for each group was determined. The sum of the averages was 266 s, so each value was reduced slightly to give a total of 248 s. The resulting idle lengths were 0, 0, 0, 2, 3, 5, 8, 10, 12, 14, 16, 18, 20, 21, 24, 26, 30, and 39 s. The 20 s value was selected for the initial idle period. The remainder were distributed between the various driving segments using the actual idle times recorded on trip 2 as a guide. In Fig. 2, the shaded areas represent the parts of the LA 4 road route which were retained in the EPA Urban Dynamometer Driving Schedule (UDDS). (See Table 3.) The route selected, and indeed each route tried, maintained the original sequence of profiles as they were recorded. The driving schedule, in this form, was presented as proposed rule making in the Federal Register (6). Comments received from vehicle manufacturers and from dynamometer manufacturers indicated that some of the low-speed acceleration rates exceeded the dynamometer design rate of 3.3 mph/s. This primarily occurred during deceleration. Where this occurred, the acceleration rate was cut back to 3.3 mph/s.

COMPARISON OF EMISSIONS

The final step in the development of the UDDS was to compare emissions from vehicles driving the UDDS to the emissions from the same vehicles driving the full LA 4 driving schedule. Statistical analysis of the results indicated that the UDDS does represent the LA 4 route. (See Table 4, and Figs. 5-7).

The 1372 data points which are listed in the Federal Register (6, 7) were transcribed by hand from the original speed profile chart so that the UDDS could be accurately described. curately described.

Scott Research Laboratories, Inc., as a part of their CAPE-



DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase®
Smarter legal research.