ROLLER BENCH URBAN CYCLES IDENTIFICATION FOR LIGHT COMMERCIAL VEHICLES FUEL CONSUMPTION

Laura Borgarello[1], Enrico Galliera

Interiors & Thermal Systems - Vehicle Dynamics & Fuel Economy, Research Centre FIAT, Orbassano-Turin, Italy

Andrea Avanzo, Adriano Fagiano

Quality Evaluation, IVECO, Turin, Italy

Abstract. *This article describes the general approach and some statistical details regarding a part of a programme in collaboration between the Research Centre Fiat and IVECO. Aim of the project is the evaluation of fuel consumption of commercial vehicles in real conditions on roller bench through a set of different cycles representative of different contexts. In particular, this article describes the approach used to identify cycle representative of light commercial vehicles in typical urban environment conditions. Core part of the article is the statistical approach used to find out synthetic cycles departing from the database of the measures obtained during the experimentation on the road.*

Keywords: *Cycle identification, Fuel consumption, Simulation study, Roller bench, Multivariate analysis.*

1. INTRODUCTION

The ever more competitive automotive market place and the growing attention to maintenance costs on the one hand and to environmental impact on the other, requires an increased awareness of end vehicle-user's requirements in terms of fuel consumption and performance. The main challenges to achieve this aim are an adequate description of mission profiles and relative engine usage together with the development of an evaluation system that correlates subjective vehicle driver's on-road perception to physical test bench targets. This permits the translation of the customer's requirements into engineering targets and, consequently, a focused development programme to achieve the goal of customer satisfaction.

[1] Laura Borgarello, email: laura.borgarello@gmail.com

To this aim IVECO is developing different tests to evaluate fuel consumption that are representative of the main real usages for each class of vehicles.

The first step is the individuation of pivot vehicles (most representative) and relative typical usages (percentage of driving in different conditions: motorway, extraurban or urban, full or partial load,..) in order to define the situations that have to be investigated.

The second step, for each interesting situation (es. motorway for fully load truck, urban context without slope for light commercial vehicles,), is the determination of representative route for the on-road measurements of fuel consumption. At this stage each vehicle repeats the representative missions on the road different times in order to evaluate the distribution of fuel consumption measurements. Each mission will be called also “real cycle or “mission.

The last step is the definition for each situation of a compressed or “zipped mission cycle (20’-40’) to be executed on the test bench reproducing the cinematic, engine usage and fuel consumption in lt/100km as the real on-road mission. This cycle will be named also “synthetic cycle.

The reasons for reproducing a synthetic rolling road test cycle are:

– elimination of uncontrolled factors such as traffic and weather,
– controlled driving style according to selected mission profile,
– fast evaluations (20-40 minutes instead of 2-3 hours),
– improve reproducibility and repeatability, and
– improved method for validation of new prototypes using both simulation and test bench instead of on-road experimentation.

This paper describes the methodology applied by IVECO and CRF to identify roller bench cycles, starting from the analysis of the on-road experimentation, for typical urban environment conditions. Indeed the methodologies previously used in other contexts (motorway, extraurban mainly) were not applicable to the urban context due to the great variability of speed in this kind of usage.

2. TEST PLAN FOR ROAD EXPERIMENTATION

Road experimentation is generally done for evaluating the fuel consumption of light commercial vehicles in urban context.

For this purpose were defined in the past two characteristic routes in Turin:

– Route A: it is a fast route in Turin simulating a trip that travels across the city,
– Route B: it is a lower route in Turin simulating a door to door delivery.

Other conditions that the working group considers interesting and that can affect the type of mission and consequently the fuel consumption are:

– the vehicle configurations (for example: axle ratio, gearshift, engine power),
– the traffic conditions,
– the driving styles.

In order to reduce and possibly evaluate the impact of these external conditions a simple experimental design was defined.

The chosen plan is a full factorial with 4 variables. The variables and related levels are reported in Tab. 1. Two repetitions of each combination of external variables have been planned during the road experimentation, with a total of 48 acquisitions.

Table 1: Variables and related levels for D.o.E.

Variable	**Levels**
Type of route	Route A, Route B
Vehicles	2 vehicles with different weight/power ratio
Traffic condition	Managed with 2 levels of time experimentation (morning and afternoon)
Driving style	Managed with 3 drivers (A,B,C)

In each test some information written by drivers in a paper generally used in this kind of road experimentation (time of driving, stop durations, global and partial consumptions, traffic conditions,..) and a time history including a predefined list of engine and vehicle variables acquired with a specific on-board system linked to the on board ECU were acquired.

All these data have been downloaded in text format and managed in SAS software for statistical analysis.

3. STATISTICAL APPROACH TO URBAN CYCLES IDENTIFICATION

The goal of the statistical analysis was to find representative cycles (velocity and gear and slope as function of time) for the real use of light commercial vehicles in urban context.

The methodology applied is based on the subdivision of each mission in cinematic sequences (speed vs. time curves between subsequent stops). These sequences have been studied in order to create groups of similar sequences, select the most representative profiles to be repeated on roller bench and evaluate frequency of groups in real missions in order to estimate the consumption on missions.

The full statistical approach will be described in the following paragraphs.

The methodology is in part original and in part derived from literature. In particular, the subdivision of missions in cinematic sequences and their subdivision in homogenous groups is derived from different papers (Rapone *et al.,* 1995; André *et al.,* 1995), nevertheless the choice of parameters is original. The selection of most representative profiles using discriminant analysis is described also in literature (Rapone *et al.,* 1995) but we used more information to select our representatives; the use of weights related to distance covered in each groups of sequences in real missions to estimate global consumption is original. The first part of the approach (subdivision of a trip in sequences and their grouping) has been applied by C.R.F. also in previous works (Borgarello *et al.,*2001).

3.1 CINEMATIC SEQUENCES

Each test has been divided in cinematic sequences. A cinematic sequence indicates the speed vs. time curve between successive stops (speed = 0). The stop time is always reported at the beginning of the sequence.

An example of sequence is shown in Fig. 1.

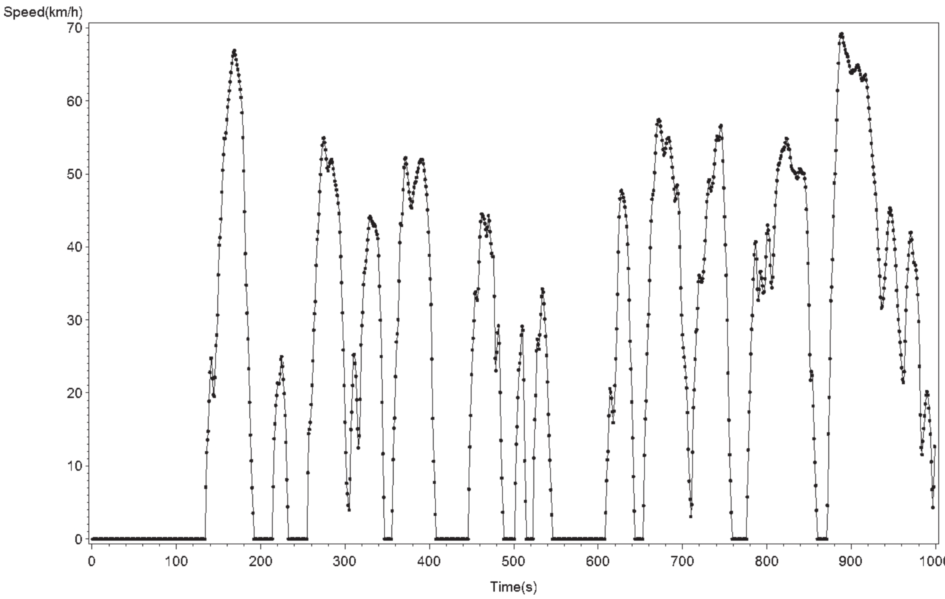

Fig. 1: Example of sequence.

Each sequence has been described by characteristic statistical parameters related to:

– driving profile (duration, stop time percentage, average running speed, acceleration and deceleration, percentage of time with constant speed, percentage of time in different gears, rpm and speed at the gear changes,…),
– engine functionality (cut-off percentage, engine torque mean and percentage over some limits,…),
– fuel consumption (l, l/100km, l/hour).

In the following, each sequence has been considered completely described by the above-mentioned parameters.

3.2 CLASSIFICATION OF SEQUENCES

In order to analyse the on-road gear shift usage, the sequences have been split into two macro-groups: the first macro-group with only 1-2-3 gears and the second with sequences in which also the 4th gear is engaged.

Links between variables describing driving profiles and fuel consumption have been considered in every group, using correlation and principal component analysis in order to choose a list of parameters describing the different cinematic profiles.

For each macro-group of sequences have been applied univariate and multivariate statistical procedures in order to obtain groups of homogenous sequences:

– Univariate outlier detection has been done considering distribution of data (in particular percentiles and quartile distances) in order to exclude strange values;
– The principal component analysis (proc princomp) on cleaned data permitted to obtain a small number of variables describing the greatest part of variance (4 principal components explain about 75% of variance in both the macro-groups);
– A non-hierarchical clustering procedure (proc fastclus) eliminated multivariate outliers and grouped the other sequences in pre-clusters;
– A hierarchical clustering procedure (proc cluster) using the Euclidean distance and the "average linkage" method permitted to group sequences in 10 cluster and 2 of them (one for each macro-group) have been excluded because too small (assimilated to outlier groups).

In this way 8 groups of sequences have been identified. Tab. 2 reports the average values of each cluster.

Table 2: Mean values of each cluster

Cluster	Cluster name	Number of sequences in group	Length (km)	Time (s)	Stop time (%)	Average moving speed (km/h)	Constant speed (%)	Average acceleration (m/s2)	Average deceleration (m/s2)
1	Long	504	0.730	103	26	32.9	41	0.75	0.95
2	Long Fast	410	1.513	150	23	45.9	52	0.77	0.96
3	Fast Accelerate	457	0.598	84	33	37.3	29	0.89	1.09
4	Med. Accelerate	477	0.239	59	36	21.1	27	0.83	0.86
5	Med. Constant	362	0.343	64	19	21.5	43	0.70	0.84
6	Micro	227	0.038	20	41	8.4	27	0.71	0.79
7	Long stops	241	0.100	64	67	13.9	29	0.83	0.79
8	Slow Accelerate	157	0.129	36	38	19.0	16	0.97	1.16

3.3 REPRESENTATIVE SEQUENCES AND ROLLER BENCH CYCLE DEFINITION

It is useful to have, for each cluster, one or more sequences that represent the cluster itself and that could be tested on roller bench in order to measure the consumption of this type of sequences.

In order to select the most representative sequence of the cluster, a discriminant analysis has been performed in the space of the descriptive variables common to both macro-group of sequences.

Using the result of this discriminant analysis (proc discrim of SAS[2]) and Euclidean distances, we use three criteria to choose the sequence that better represents groups:

– posterior probabilities obtained by the discriminant analysis,

– group-specific density estimate obtained by the discriminant analysis, and

– the distance from the center of the group in the space of the principal component.

The proposed representative sequences have been also evaluated in simulation in order to exclude "strange" or infeasible sequences.

In order estimate fuel consumption for each group of sequences we need to measure some of them on roller bench for each group.

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[2] This procedure supposes that each group has a multivariate normal distribution and develops a discriminant function or classification criterion by using a measure of generalised squared distance.

To better manage the experimentation it is better to have a unique cycle to repeat on roller bench measuring partial fuel consumption instead of 8 different cycles. Moreover this cycle has to be not too long in order to be executable by drivers (30-45 minutes is a reasonable time) and to have a minimum consumption for each cluster in order to avoid large measurement errors.

For this reason we decided to use more representative sequences (chosen among the 4 best representatives) for each group in order to reach about 5 minutes and a minimum consumption for each cluster.

The order of sequences' execution has been chosen according to the frequencies of succession of group of sequences and the objective difficulty to execute on roller bench some type of sequences (more difficult sequences are at the end of the cycle).

The speed profile of the defined cycle is represented in Fig. 2.

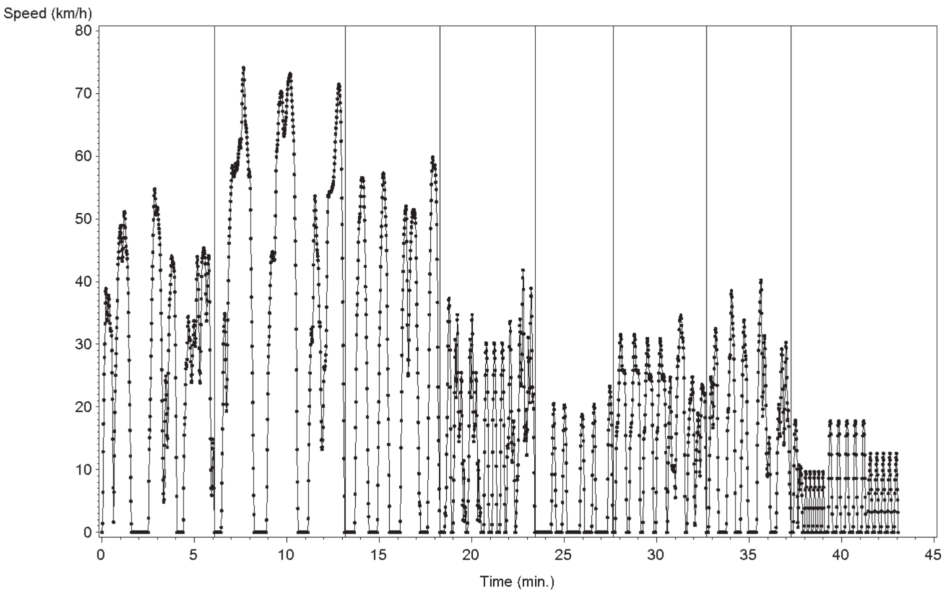

Fig. 2: Speed profile of synthetic cycle
(the order of sequences clusters is 1 2 3 8 7 5 4 6)

The roller bench needs, in addition to the speed profile, a slope profile that, in this case, is assumed constant and equal to zero and a gearshift time history.

CRF and IVECO developed a "gear shift algorithm" based on the analysis of behavior of professional drivers that permits to adapt the cycle to different vehicles considering the weight, full load engine characteristics and gearbox ratios. This tool is an internal software still under revision, hence no public documentation is available.

3.4 GROUPING MISSIONS

For the fuel consumption estimation the link between the groups of sequences and the external condition has to be evaluated through univariate and multivariate approaches.

In particular we evaluated the impact of external conditions considered in the experimental design (type of route, vehicle, traffic condition, and driver) on:

– some statistics on the global mission related to cinematic/ engine/consumption, and
– number of sequences in each cluster.

Both these analyses highlighted the type of route as significant variable and the other variables as less important; the vehicle is important only on some engine and fuel consumption parameters.

Starting from these analyses it has been decided to consider only two types of missions related to the two types of routes, and to estimate global consumption for these missions.

3.5 FUEL CONSUMPTION ESTIMATION FOR THE MISSIONS

The consumption estimation for the two selected road missions for a generic vehicle is possible starting from partial measurements of fuel consumption on synthetic cycle using a weighted mean. The weights have been calculated considering the percentage of distance travelled in each group of sequences. The partial measurements of consumption used in the weighted mean must be expressed in l/100km.

Both the reduced cycle and weights have been introduced also in the simulation tool PerFECTS® developed by CRF and FPT. This tool lets users evaluate fuel consumption of a vehicle on standard driving cycles (NEDC, FTP75, Highway, US06, Artemis,…), user-defined cycles (including the two urban missions now considered), actual missions from road recordings, with cold and hot start; altitude and/or grade and/or road curvature radius are taken into account. More details on this tool are available in Piu *et al.* (2011).

4. VALIDATION OF RESULTS

This approach has been validated during all the process and before the experimentation on roller bench with the simulation tool PerFECTS¨ in order to evaluate the feasibility of reduced cycle and compare fuel consumption with on-road acquisitions.

The validation has been concluded with a set of experiments on roller bench with the same vehicle used in the road experimentation. Different executions of the cycle has been tested in order to evaluate the dispersion of results, then the mean fuel consumption of each cluster has been considered in the weighted means to estimate the consumption of the two routes for the vehicle itself.

These calculated values are coherent with the distribution of acquired data; the estimated value is inside the interquartile range and 1 standard deviation from the mean.

5. CONCLUSIONS

The adopted statistical approach permits the generation of a synthetic cycle for roller bench representative of urban context, where the approaches used in the past for cycles generation of other contexts (like highway or extra urban) were not applicable.

This cycle reproduces the main types of cinematic profiles acquired during the road experimentation, measuring relative fuel consumption and allows a good estimation of the fuel consumption for the 2 routes. Furthermore, the "gear shift algorithm" permits to adapt the cycle to vehicles of the same class but with different full load engine characteristics and gearbox ratios.

The use of this cycle, both on roller bench and in simulation tools for fuel consumption estimation, is very useful for comparing benchmark analysis or for testing different technical solutions for a prototype. This method is also preferable to on-road experimentations in term of cost, time and repeatability of the tests.

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