MIRAN ZGONIK, Ph. D.
E-mail: miran.zgonik@fpp.uni-lj.si
University of Ljubljana,
Faculty of Maritime Studies and Transport
Pot pomorščakov 4, SI-6320 Portorož, Republic of Slovenia
FRANČIŠEK BIZJAN, Ph. D.
E-mail: francisek.bizjan@guest.arnes.si
University of Ljubljana, Faculty of Mechanical Engineering
Aškerčeva 16, SI-1000 Ljubljana, Republic of Slovenia

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COMPARISON OF ENGINE POWER EXPLOITATION BETWEEN NORMAL AND DYNAMIC DRIVING IN REAL TRAFFIC CONDITIONS

ABSTRACT

The increase of cars engine power has reached critical limits, so that further increase would make no sense, since already the real traffic conditions now do not enable its reasonable exploitation. Experiments have confirmed that there is no essential difference between the more or less powerful cars in combined traffic in and near towns, particularly when fully complying with traffic regulations. For the evaluation of the car "adequacy" a non-dimensional criterion number Nv was proposed. This number rises with the rising weight (safety), speed, lower fuel consumption and faster acceleration. The usual Nv values at 100km/h are between 1 and 3 for the majority of ordinary cars. Statistics comprising a great number of cars in the past decades showed that the said criterion number turned out to be an adequate parameter for the assessment of development trends. Experiments showed that a higher criterion number value in real traffic does not represent much advantage even in dynamic driving.

KEY WORDS

vehicles development trend, maximum and exploited engine power, normal and dynamic driving, non-dimensional criterion Nv

1. INTRODUCTION

Our civilization is obsessed with speed. Everyone is rushing, because everyone else rushes; as much, as far, as fast as possible, although it is at the expense of energy. The value of time and space is increasing since they are limited for human life. We are witnessing the growth of material goods, except for the supplies of the simple transformable energy which are growing scarce. Fuel consumption to satisfy the longing for "as much as possible" and "as far as possible" is about proportional, however to satisfy "as fast as possible" the interdependence is almost squared. This is most evident in traffic, as the energy consumption is growing with the growing number of users, heavier cargo carried and higher speeds achieved. The consumption of coal increased in 100 years 10 times, of oil 200 times and electricity 1000 times.

The main reason for such increase in the consumption is the growing traffic. Before 1970 no alarm was raised because of limited supplies of oil. Only the long-sighted were worried. Political instability in the countries with larger oil reserves was more of a problem. There was a sudden change between 1970 and 1980 when we witnessed first shocks due to the unexpected drastic price rises and disturbances in oil supplies. Oil consumption of car engines, though less powerful ones, was high and traffic sharply increased also in poorer countries. And it could have increased even more, had the price of cars not been too high. Similar explosion of motorization is taking place nowadays in China.

There was a challenge to point out the actual needed power for vehicles in real time traffic (so that all traffic participants would strictly observe the traffic rules), and how the personal vehicle's power has unnecessary increased in last thirty years. The increase of power and car's improvement has been evaluated in non-dimensional format. We introduced a new characteristic number "Nv" for our non-dimensional study; meanwhile the data for outcoming vehicles were taken from catalogues (literature 7). Practical measurements in real time traffic circumstances were done in the wide Ljubljana area with ascertainment that the gained time is more depended on driver abilities and experience than the car's performance itself and/or "Nv" number.

2. EXISTING DEVELOPMENT TRENDS OF CARS

Many factors influence the consumption of fuel in real traffic. The most important are: engine efficiency, aerodynamic and rolling resistance, car mass, acceleration frequency and the way of braking, conservation of brake energy and traffic regulation. Apart from the car mass they all depend also, or even above all, on speed.

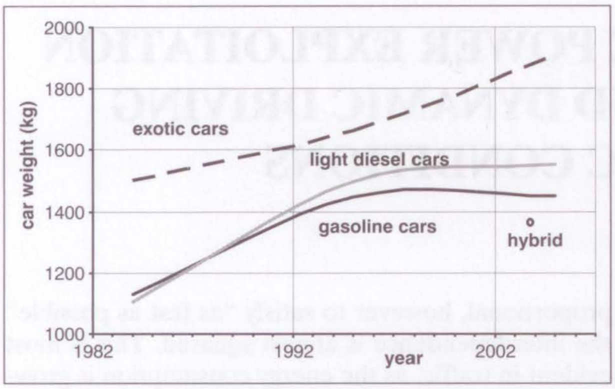

Figure 1 - Average mass of all new types of cars in the past years

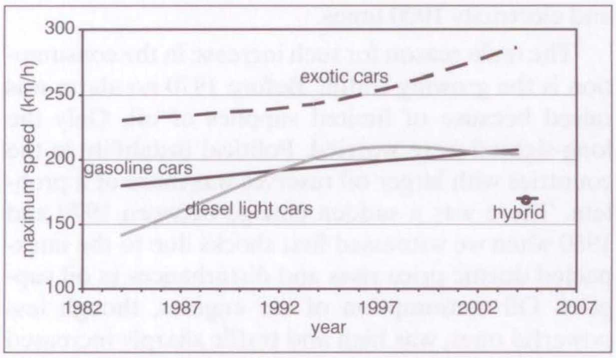

Figure 2 - Average maximum speeds of all new types of cars in the past years

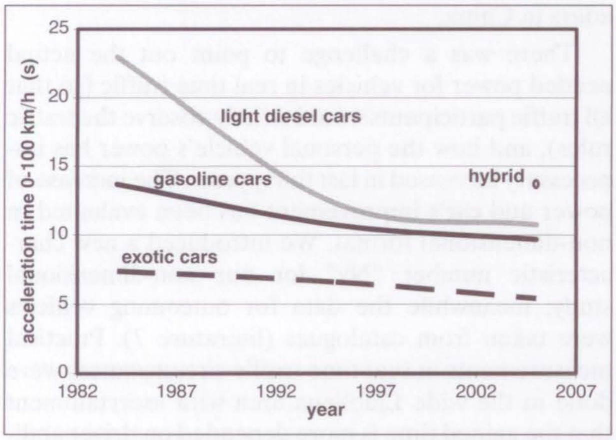

Figure 3 - Average acceleration times at 0-100 km/h of new types of cars in the past years

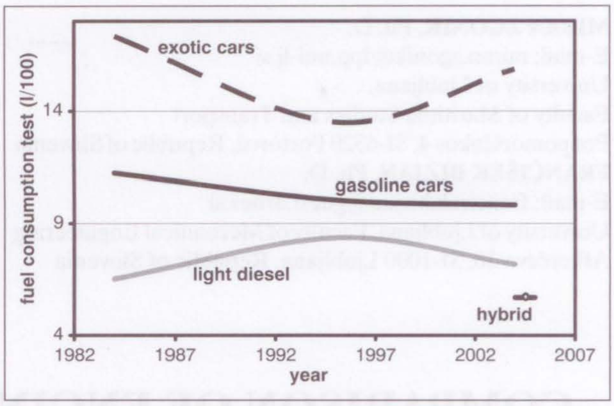

Figure 4 - Average specific fuel consumption at 100 km of new types of cars in the past 20 years

Figures 1, 2, 3 and 4 show the increase of the cars mass and maximum speeds, reduced times of acceleration and reduced specific fuel consumption. Average values for cars were calculated on the basis of the new types that came on the market and not on the number of sold cars. The "statistics" is obviously influenced too much by different types of bigger cars, but fewer produced and sold.

3. NON-DIMENSIONAL CRITERION NV

A non-dimensional criterion Nv is proposed for "fairer" comparison of cars of different sizes as to acceleration and fuel consumption. This is obtained from the proportion between the "desirable" and "non-desirable" features. The former are: optimum mass due to safety and comfort as well as the necessary speed, and the latter: acceleration time to that speed and energy consumption at that speed per meter of the travel length.

$$N_v = \frac{m \cdot v}{t \cdot E}[-]$$

The units are reduced; the expression is non-dimensional. For everyday use it can be transformed, so that we replace the energy consumption per meter traveled with the fuel consumption B in liters per 100 km at the referred speed, considering calorific value and density of fuel of course. And instead of speed (m/s), for the cars a more usual unit (km/h) is used. In the expression therefore, the convertible factor k appears.

$$N_v = \frac{m \cdot v}{t \cdot B \cdot k}[-]$$

If speed is in km/h and the consumption B in l/100km, the factor k depends on the calorific value H_i (J/kg) and density ρ (kg/l) of the fuel used. Considering the transformation of units it is calculated with the expression:

$$k = \rho \cdot H_i \cdot 3.6 \cdot 10^{-5}$$

For the usual fuels we obtain as follows:
for gasoline with the calorific value 43.2 MJ/kg
and density ρ=0.75 kg/l k = 1166;
for diesel oil with the calorific value 42.7 MJ/kg
and density ρ=0.83 kg/l k = 1277;
for methanol with the calorific value 20 MJ/kg
and density ρ=0.795 kg/l k = 572.

The proposed criterion number Nv for the individual vehicle at different speeds is certainly different. The values of Nv are expected to be as high as possible and fall the least with the rising speed. Figure 5 shows average dependence on speed for different kinds of cars, and Figure 6 shows the correlation between the basic price and the criterion Nv at 100km/h for all new types of cars which appeared on the market in 2004.

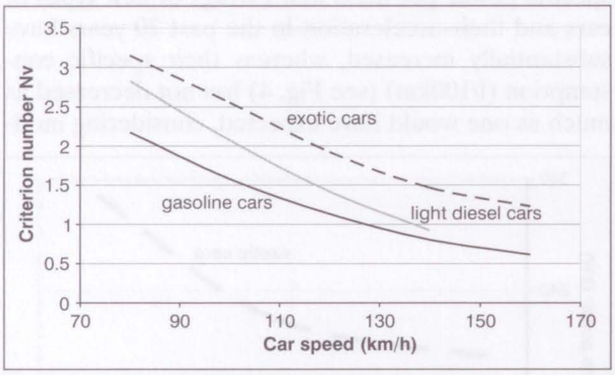

Figure 5 - Dependence of the criterion Nv on speed for the new kind of cars in 2004

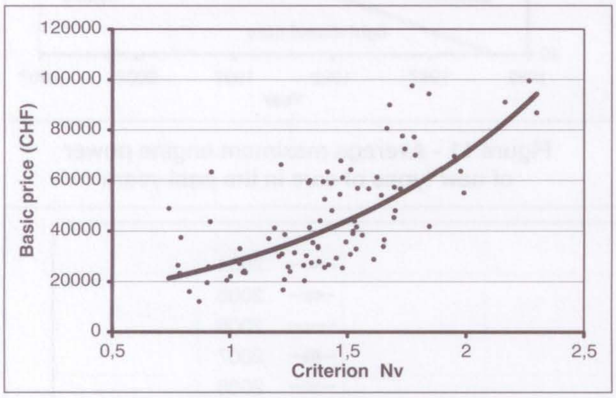

Figure 6 - Correlation between the basic price and the criterion Nv at 100km/h for all new types of cars in 2004

Figure 7 compares the criterion Nv and the basic price for different new types of gasoline cars in 1984, when they were without catalysts, with the year 1995, when all new cars were fitted with them. We see that the 1995 line is rising above the line 1984, i. e. the cars became better and consequently more expensive. However, if we considered the inflation which applies also to the Swiss frank, newer cars would be relatively cheaper, which can be attributed to larger series of better cars.

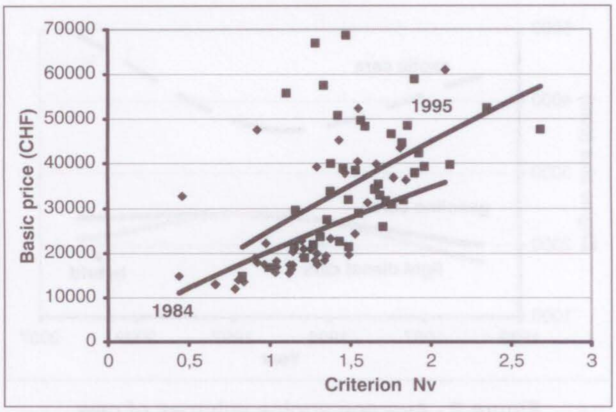

Figure 7 - Comparison of correlation between the basic price and the criterion Nv (at test consumption and at 100km/h) for different new types of cars in 1984 and 1995

The criterion could also be used for the assessment of adequacy or adaptability of individual cars in real traffic conditions. A car in different road segments has in real traffic different criterion numbers Nv due to different fuel consumption, average speed and acceleration time. The obtained Nv should be compared with the Nv calculated in ideal conditions. The cars, where the criteria differ less, offer more of what is promised while purchasing than those, where the difference is greater. Analogically, we could compare the impact of driving styles of bad and good drivers or the impact of various traffic conditions on the same vehicle with the same driver. But such research is comprehensive and cannot be carried out without a user.

4. NECESSARY ENGINE POWER

As there is a squared increase of drive resistance with the rising speed, the necessary engine power rises for one power more. And if we wish to achieve a certain speed as soon as possible, we need additional power for acceleration, particularly if the vehicle is heavy. Due to dynamic driving the installed engine power must be much higher than the one required for normal transport. It is not only haughtiness but also traffic conditions which dictate how much power is still reasonable. In dense and slow traffic high maximum power is useless. It only causes higher fuel consumption, as too powerful engines operate almost all the time lightly loaded, when efficiency is low.

Interesting is the disproportion between average engine size of all types of cars supplied on the world market in a definite period of time and all types of actually sold cars. Figure 8 shows an average engine size in cm^3 for the past 20 years, and Figure 9 shows the data of producers for the past 5 years and the forecast for the following five years. There are more powerful engines supplied on the market; however, the power

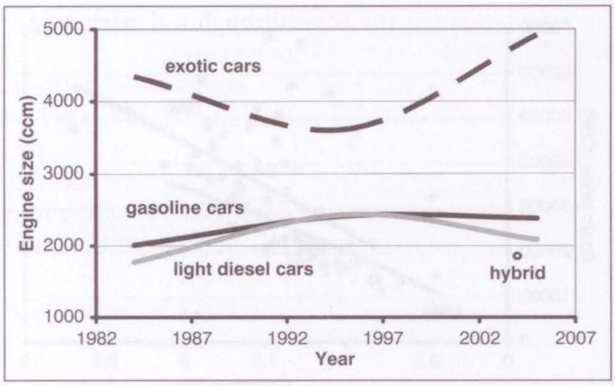

Figure 8 - Average engine volumes of new types of cars in the past years

of the largest number of sold cars varies between 1300 and 2000 ccm. These are produced in larger series. It seems that common sense prevails.

Fierce competition at the same physical law for all forced the car producers to produce cars with similar specific fuel consumption (l/100km) for comparable cars within the optimum operating range, and between the most modest and the most extravagant ones at a ratio 1:2. The powers of the installed engines differ incomparably more. However, too powerful an engine rarely operates in the optimum range.

A heavier car logically requires more power; but how much more?

While purchasing a car, many factors influence our decision. These are shown in Figure 10.

We are tempted by some factors to select greater power. Others, quite the contrary, force us to be more reasonable. Taking a balanced decision is not easy. Figure 11 shows what cars came on the market in the past 20 years. Due to the more and more dynamic traffic we wish for solid and safe cars. In spite of modern technology and lighter materials, the mass of cars is today larger on the average than before, and so is the maximum engine power. Given that, also the installed specific power per mass unit (W/kg) of new types of cars and their acceleration in the past 20 years have substantially increased, whereas their specific consumption (l/100km) (see Fig. 4) has not decreased as much as one would have expected, considering mod-

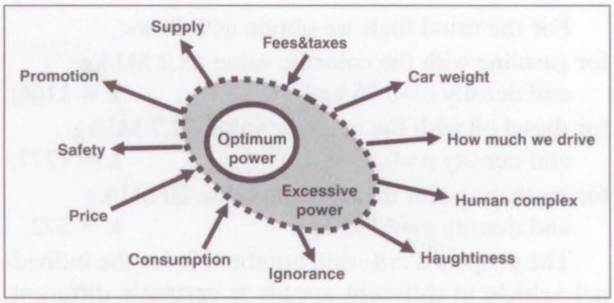

Figure 10 - Factors influencing selection of engine power

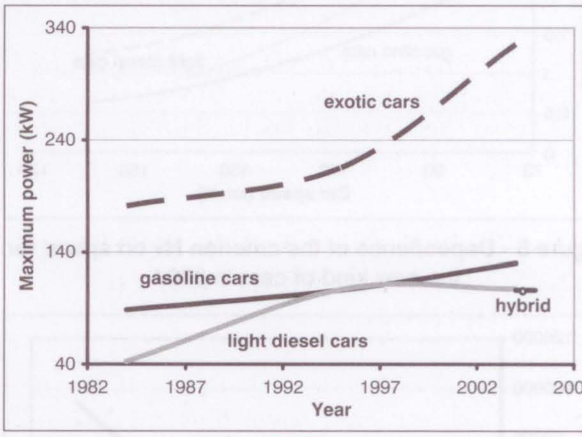

Figure 11 - Average maximum engine power of new types of cars in the past years

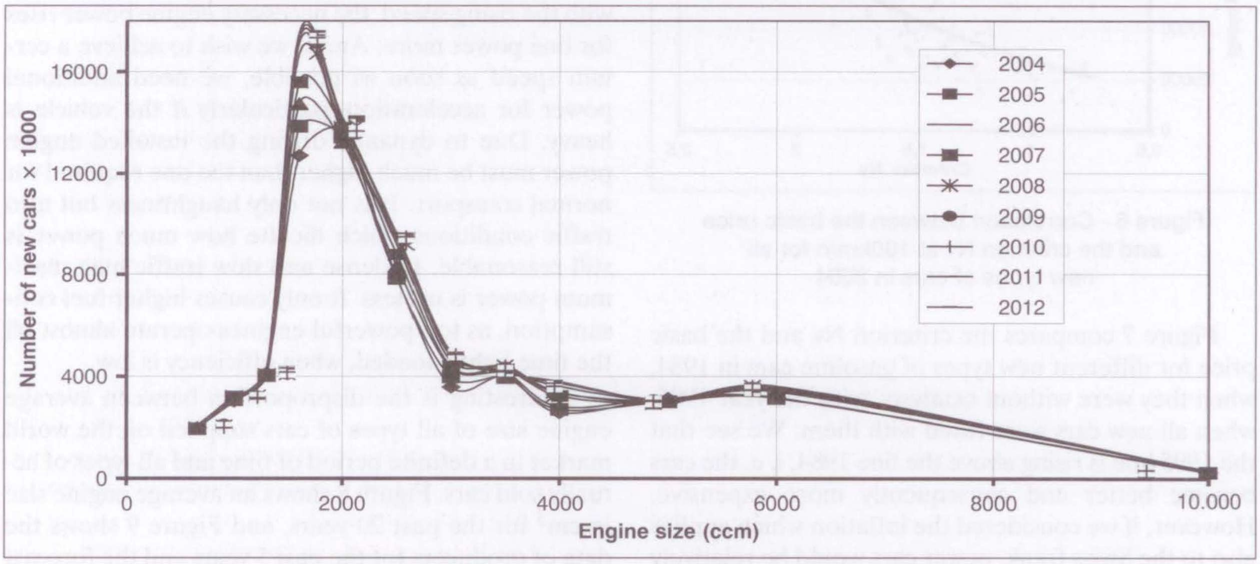

Figure 9 - Number of new cars with various engine volumes and the forecast by producers for the following 5 years

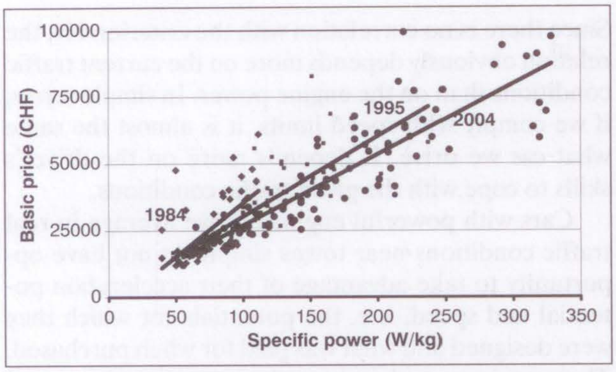

Figure 12 - Relation between specific car power (W/kg) and its price in different periods

ern, incomparably better engines with the microprocessor regulated combustion and better fuels. An average consumption has fallen insignificantly for the very fact that relatively more powerful engines have been installed, predominantly much more powerful than necessary. However, greater specific power costs more; therefore, such cars are more expensive (Figure 12).

We can firmly assert that in order to achieve lower fuel consumption it is more useful to select the right engine power and adequate driving than some percent better engine efficiency.

5. ASCERTAINING ENGINE POWER EFFICIENCY IN REAL TRAFFIC CONDITIONS

The research aimed at finding out how much of their available maximum power different cars really exploit in real traffic conditions and how much it is different when complying or non-complying consistently with speed limits. It also wants to ascertain how much time is actually saved when violating speed limits, and finally, the goal was to find out what power would suffice also in dynamic driving. Safety aspects were not dealt with in this research.

5.1 Experiment concept

Different cars were driven always by the same driver who was also experienced in fast and dynamic driving. He was familiar with the track and traffic conditions. We did our best to provide similar traffic conditions. All measurements took place every day at the same time. The test track was leading from the outer edge of Ljubljana downtown to its suburbs and the other way back (see Fig. 13).

The track consisted of four legs: from downtown along the bypass motor road 9.16 km (points 1-2), the regional road 3.84 km (points 2-3), the suburban road through a sparsely populated area 3.5 km (points 3-4) and 1.6 km along the road through a densely populated area back downtown (points 4-1).

For the starting point the comparison between driving when complying with traffic regulations and dynamic driving with four different types of cars, two with gasoline and two with diesel engine was selected. However, our intention was not to compare these four vehicles with each other, as they were very different as to weight and purpose, although later it turned out that there was no essential difference between them when the driver complied with regulations.

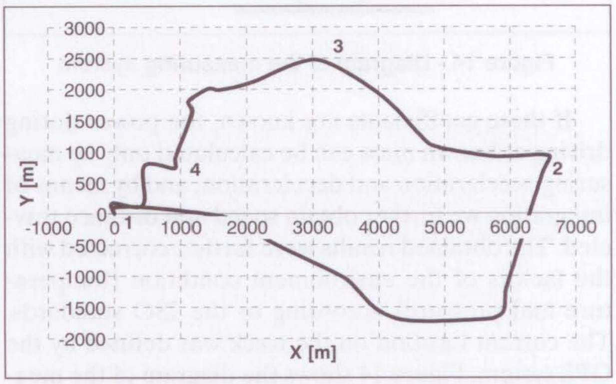

Figure 13 - The test track with the designated legs, total of 18.1 km

In the chapter above the non-dimensional criterion Nv for each of them was calculated. The data considered, such as mass, acceleration and consumption at 100km/h were provided by the producers.

The following cars were tested:

- Small car with gasoline engine
  P=64 kW (Toyota Yaris), $N_v = 1.048$
- Large car with diesel engine
  P=160 kW (BMW 730 D), $N_v = 2.428$
- Single space car with gasoline engine
  P=90 kW (Hyundai Matrix), $N_v = 1.151$
- Pickup car with diesel engine
  P=55kW (MB Vaneo CDI), $N_v = 1.103$

On the said track the momentary power was measured for each car in real traffic conditions; first, during driving strictly complying with traffic regulations, however with the speed allowed by traffic conditions; and second, during dynamic driving, with reasonable, still non-dangerous exceeding of speed limits; however, intending to complete the ride as soon as possible. The figures below designate the said ways of driving with "normal" and "dynamic".

The developed momentary power (on the wheels) was ascertained by measuring acceleration and deceleration with the DAQ instrument with the connection for GPS antenna (CEP 5-7 m). For each car a calibrated test according to the manufacturer's protocol was carried out, so that the computer program of the instrument could measure and adopt the coefficient of both, the rolling and the air resistance.

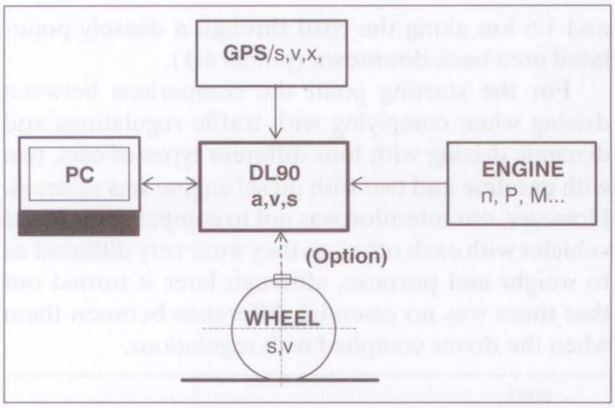

Figure 14 - Diagram of the measuring system

If these coefficients are known, the power during driving at known mass can be calculated only by measuring acceleration and deceleration, and by means of integration we further obtain speed and distance traveled. The obtained results were further corrected with the factors of the environment condition (temperature and pressure) according to the ISO standards. The current location on the track was defined by the GPS system. Figure 14 shows the diagram of the measuring system.

5.2 Measuring results

First, we were interested in the time saved in real traffic conditions near towns, strictly considering the speed limit and when exceeding speed limit in order to arrive at the destination point as soon as possible. Figure 15 shows that the saved time on the 18km-long way is on the average about 220 seconds, i. e. about 3.5 minutes for all vehicles. The time saved is not even sufficient to have a cup of coffee. Detailed analysis showed that even the said minutes do not depend entirely on the car. The correlation of the saved time with the criterion Nv for all cars in the previous paragraph was not significant. This is shown in Figure 16.

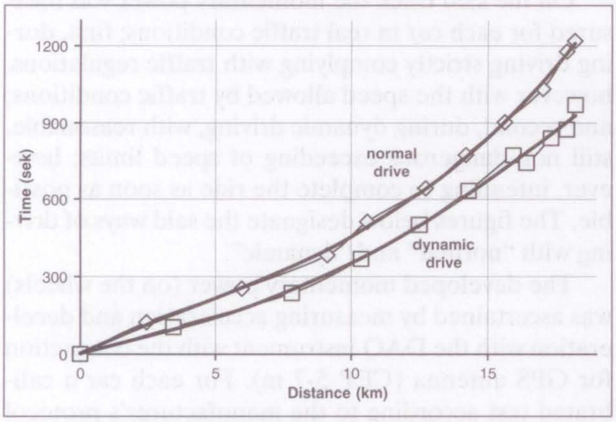

Figure 15 - Average saved time in normal driving, considering speed limits and the fast, dynamic driving for all four cars

Since there is no correlation with the criterion Nv, the relation obviously depends more on the current traffic conditions than on the engine power. In simple terms, if we comply with speed limits, it is almost the same what car we drive. It depends more on the driver's skills to cope with the given traffic conditions.

Cars with powerful engines above average in real traffic conditions near towns simply do not have opportunity to take advantage of their acceleration potential and speed, i. e. the potentials for which they were designed and what was paid for when purchased. Their engines rarely approach maximum power, and when they do, it is in short time intervals.

However, there are advocates of powerful engines arguing that we gain very much in real traffic conditions as well if the car "drags" properly. Consequently, in their opinion, powerful engines are necessary. Further experiment, therefore, intended to challenge their claims. Two cars were compared (Figures 17 and 18) in normal and dynamic driving, a powerful and expensive BMW 730 D with the criterion $N_v = 2.428$ and a much smaller and cheaper Toyota Yaris $N_v = 1.048$. Very similar conditions of low power exploitation were ascertained also with all the other tested cars.

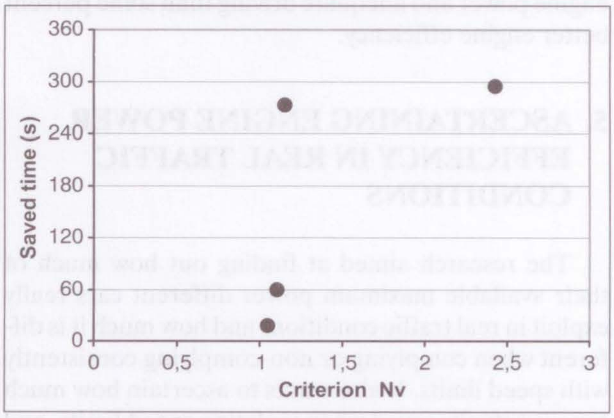

Figure 16 - Saved time in dynamic driving, i. e. without consideration of speed limits depending on the criterion Nv

Graph in Figure 17 shows the percentage of exploited nominal power of the BMW car on the test track, in normal and dynamic driving. We can see that in normal driving (gray curve) only for a short time the maximum 38% of power is exploited and most of the time only 5%. In dynamic driving up to 45% of power is exploited and most frequently also none. Fuel consumption and gas emissions are higher in such driving.

Figure 18 shows the same for Yaris. We can see that in normal driving also up to 30% of its nominal power is exploited (gray curve), but several times more frequently than the BMW and most of the time only about 5%. On the other hand, up to 80% of power is exploited in dynamic driving and most of the diagram sharp ends show from 50 to 60% in much

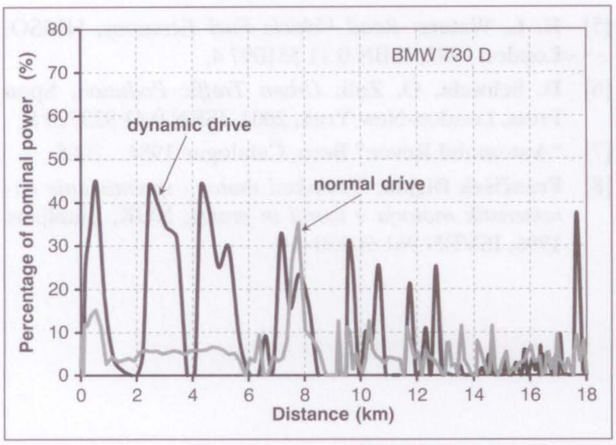

Figure 17 - Percentage of developed power in normal and dynamic driving for the BMW 730D

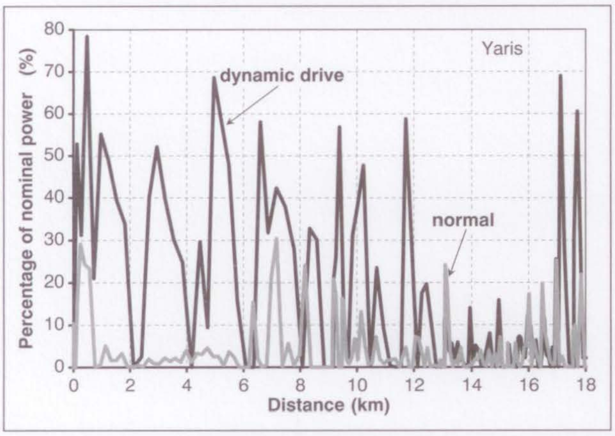

Figure 18 - Percentage of developed engine power in normal and dynamic driving for Toyota Yaris

more frequent intervals than was the case with the much more powerful BMW.

If a hybrid car was tested, the energy for sharp ends would be replaced by electric accumulation, and for most of the rest of time a less powerful gasoline or diesel engine could be used.

6. CONCLUSION

The paper shows that constant increase in car engine power, typical for the past decades, has reached limits and it would make no sense to increase it any further, as real traffic conditions already at present do not enable its exploitation. It is expected that due to the growing traffic density there will be even less chance for that in the future. Therefore, purchasing of powerful engines has no economic grounds. The experiments have proven that destinations can be reached in the same time with less powerful engines as well, when complying with traffic regulations. And these will have to be even more strictly complied with in the future.

The research proposed and used a non-dimensional criterion number Nv for the evaluation of the car "adequacy", which rises proportionally with the rising weight, speed and decreasing consumption per unit of distance traveled and faster acceleration. The usual Nv values at 100km/h are between 1 and 3 for the majority of ordinary cars.

Obviously, more expensive modern cars have higher criterion numbers than slower and heavier older ones. Statistics comprising a great number of cars in the past decades (until 2005) showed that the said criterion number turned out to be an adequate parameter for the assessment of development trends. Experiments showed that a higher criterion number value in real traffic does not represent much advantage even in dynamic driving, and almost none when complying with traffic regulations.

Dr. MIRAN ZGONIK
E-mail: miran.zgonik@fpp.uni-lj.si
Univerza v Ljubljani, Fakulteta za pomorstvo in promet
Pot pomorščakov 4, 6320 Portorož, Republika Slovenija
Dr. FRANČIŠEK BIZJAN
E-mail: francisek.bizjan@guest.arnes.si
Univerza v Ljubljani, Fakulteta za strojništvo
Aškerčeva 16, 1000 Ljubljana, Republika Slovenija

POVZETEK

PRIMERJAVA IZKORIŠČENOSTI MOČI MOTORJA V REALNIH PROMETNIH POGOJIH MED NORMALNO IN DINAMIČNO VOŽNJO

Povečevanje moči motorjev osebnih vozil je prišlo do meja, ko jih ni več smiselno povečevati še bolj, saj realne prometne razmere že sedaj ne omogočajo njihove izrabe. Eksperimentalno smo potrdili, da v kombiniranem prometu blizu mest ni bistvene razlike med vozili z manjšimi in velikimi močmi, če se tudi pri močnejših vozilih držimo predpisov omejitve hitrosti. Za vrednotenje "uspešnosti" vozila smo predlagali in uporabili kriterijsko brezdimenzijsko število Nv, ki je tem večje, kolikor je avto bolj varen (težji) in hiter, kolikor manj porabi in kolikor hitreje pospešuje. Običajna števila Nv pri hitrosti 100 km/h so za večino običajnih osebnih vozil med 1 in 3. Pri statistični analizi velikega števila vozil iz preteklih desetletij se je to kriterijsko število pokazalo za kar primeren parameter za ocenjevanje, kam gre razvoj. Eksperimentalno smo potrdili, da višje kriterijsko število vozila v realnem prometu ne pomeni velike prednosti niti pri dinamični vožnji, pri normalni pa skoraj nič.

KLJUČNE BESEDE

trend razvoja vozil, nazivna & dejanska moč motorja, normalna in dinamična vožnja, brezdimenzijski kriterij Nv .

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