CITY DRIVING ELEMENT COMBINATION INFLUENCE ON CAR TRACTION ENERGY REQUIREMENTS

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Abstract. Deviation of the real driving fuel consumption from the measured fuel economy given in vehicle specifications is a growing concern for certain groups of researchers, motorists and organizations. The motivations of the concern are from caring about the world environmental changes to very individual costs for motorists. The amount of deviation is blamed on vehicle manufacturers, car owners, service technicians and even poor country economies having more inferior roads, fuels and materials available. It is vital to differentiate between the fuel consumption variations caused by different driving conditions, driving styles, vehicle technical condition, fuel quality, car manufacturers increasing expertise of achieving or cheating low consumption test results and other factors. The paper shows vehicle driving energy requirement modeling for urban stop and go traffic at various average driving speeds. The modeling results are compared with real environment driving in the Latvian capital city Riga. Diverse driving conditions are modeled within urban driving speed limits. The car speed - time modeling function is reduced to simple and discrete constant acceleration and coast down events. The computer modeling and road test results show considerable variation of traction energy depending on the driving pattern. The paper forms an essential section in a more extensive research of fuel consumption in city driving.

Keywords: vehicle, energy usage, fuel consumption, urban driving.

Introduction

Energy saving and fuel consumption reduction are in the greatest interest of vehicle users and the whole society. Car fuel consumption is defined by manufacturers applying standardized methods and evaluated by car users from real life driving. Deviation of real driving fuel consumption from the measured fuel economy given in vehicle specifications is a growing concern for certain groups of researchers, motorists and organizations. The motivations of the concern are from caring about the world environmental changes to very individual costs for motorists. The amount of deviation is blamed on vehicle manufacturers [1], car owners, service technicians and even poor country economies having more inferior roads, fuels and materials available. It is vital to differentiate between fuel consumption variations caused by different driving conditions, driving styles, vehicle technical condition, fuel quality, car manufacturers increasing expertise of achieving or cheating low consumption test results and other factors. Adequately methods for lowering the fuel consumption have to determine which part in the fuel consumption chain of events (fuel – energy conversion – internal mechanical losses – energy usage for vehicle traction and auxiliary needs) has been optimized.

Vehicle traction energy investigation has a significant role in the fuel consumption analysis. It has become even more important with the rapid development of vehicles with alternative drive concepts, including hybrid and electric cars when new factors, such as braking energy recovery, optimizing energy flows in the vehicle, reducing the traction energy usage habits, have to be taken into account.

Having well established proof that energy requirements and fuel consumption among other factors highly depend on the driving conditions and patterns, a lot of research has been done for certain environments [2; 3]. Combining the research for certain Riga city traffic aspects with a trial to visualize the car energy demand for various driving conditions along with the testing concepts developed by professional community this research gives another insight in the vehicle fuel economy opportunities.

Materials and methods

Materials and methods for the vehicle traction energy requirements in urban traffic were selected according to the needs and techniques used in an ongoing project of fuel consumption investigation. Although the modeling has been done for various vehicle types, since the first phase of the project is partially carried out using Opel Zafira 2004 with a 1.6i-16V petrol engine, most of the calculations shown in this paper are done for this car. This simplification is used because the aim of the investigation is more traffic related than being an examination of vehicle technical characteristics.

Practical experiments were done to evaluate energy requirement limits with rapid acceleration and stop tests for high energy, and coast down tests for low energy requirements. All measurements were done after technical inspection of the car, inflating the tires to manufacturers recommended pressure, checked by professional gauge and with warmed up engine. The speed profile of the driving tests with rapid accelerations to the speed between 50 and 60 km·h^{-1} with consecutive braking is shown in Fig. 1.

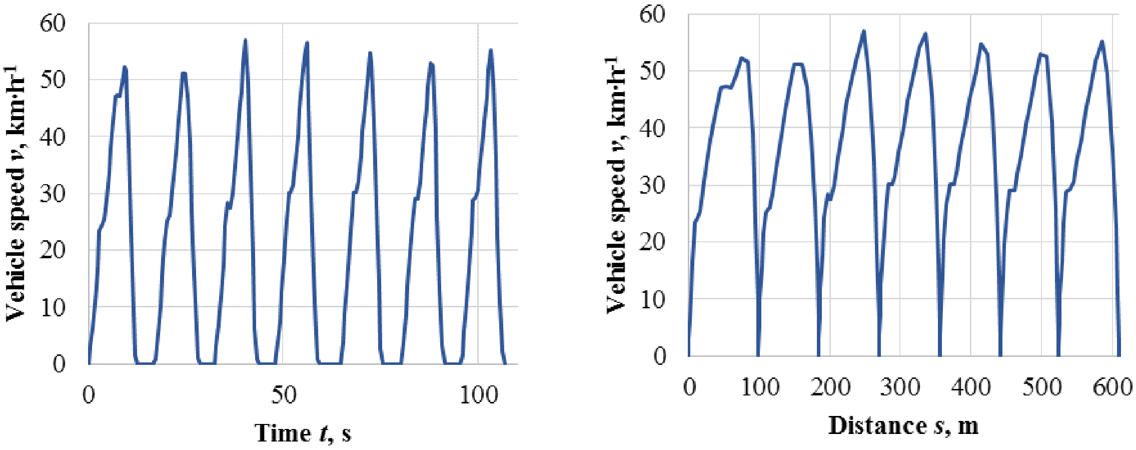

Fig. 1. **Speed profile of driving tests with intense acceleration and braking**

Vehicle speed, engine speed, fuel consumption rate and throttle opening was logged by OBD device Auterra DashDyno SPD, position and vehicle speed logged by GPS logger RaceLogic DriftBox with a 10 HZ GPS engine. The data were analyzed using manufacturers software and MS Excel.

To assess the applicability of the model used for city driving analysis, a test drive was made in Riga city covering the city center, crossing bridges, city outskirts and major incoming traffic routes. To have a reference for higher speed driving, a route fragment to Riga airport has been included. The total length of the test drive is almost 40 km. The driving path logged and exported to Google Earth is shown in Fig. 2.

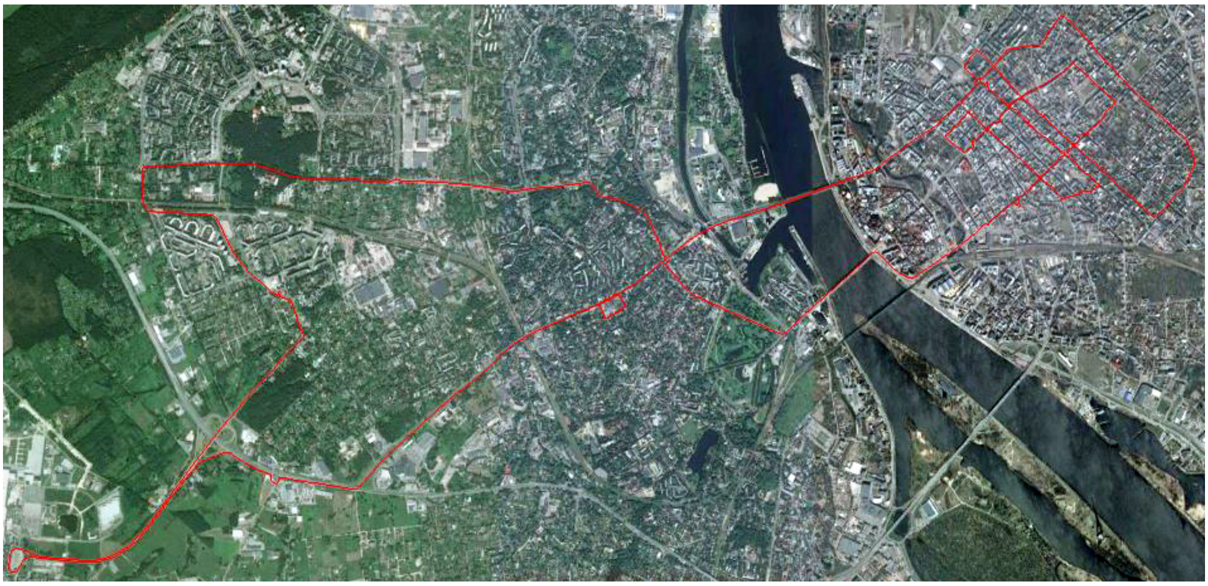

Fig. 2. **Test route in Riga city on Google Earth map**

To examine the vehicle energy requirements in stop and go traffic depending on the number of stops per distance travelled, vehicle driving was split in repeating phases: acceleration to the target speed, driving with constant speed, coasting in neutral, braking and stoppage. The simplified driving cycle with three stops per km and coasting in neutral from 50 km·h^{-1}to 40 km·h^{-1} are shown in Fig. 3.

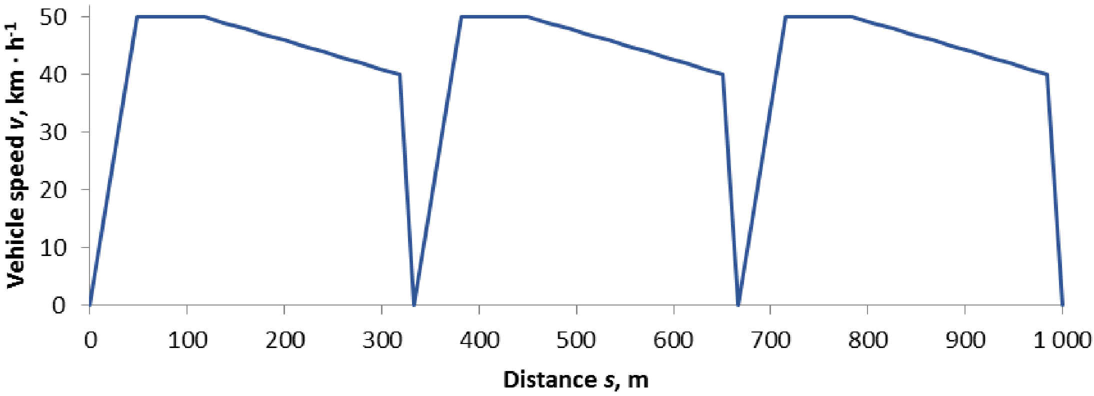

Fig. 3. **Modeled driving cycle sample with three stops per km**

For modeling the following assumptions have been made:

- Regardless of the number of stops all accelerations are done with the same intensity. The modeling has been performed with various acceleration values, but the graphs shown in the paper correspond to average acceleration from 0 to 50 km·h^{-1} equal to 2 m·s^{-2}, which is close to maximal acceleration performance for the given vehicle in this speed range.
- All braking modeling is done with the same -4 m·s^{-2} acceleration, which is quite intense to achieve more stops per km, and allows avoiding emergency braking. The value used in modeling is close to the average values of the corresponding on-road trials.
- The vehicle stoppage time influences the average speed but does not influence the traction energy; therefore the current paper presents only results without vehicle standstill.
- Coasting is modeled to selected intermediate speed values. The coasting intensity is calculated from the air drag factor $c_w{\cdot}A = 0.79$ m^2, given in the vehicle technical datasheet, and cost down test measurements giving rolling resistance for the winter tires applied $c_{rr} = 0.012$.
- Driving time with a constant speed is calculated to achieve the given number of stops per km.

All driving cycle sections are calculated at constant acceleration values for the entire acceleration or braking, except for coasting and engine braking, where values are calculated after each 1 km·h^{-1}. The traction energy A_t is calculated as a sum of the work needed for overcoming the rolling resistance A_{rr} (1), air drag A_d (2) and energy dissipated in the braking system A_b (3).

$$A_{rr} = c_{rr} \cdot g \cdot m \cdot s\,, \tag{1}$$

$$A_d = \int_0^s 0.5 \cdot c_w \cdot A \cdot \rho_a \cdot \left(v_0^2 + 2 \cdot a \cdot s\right) \cdot ds = 0.5 \cdot c_w \cdot A \cdot \rho_a \cdot \left(v_0^2 \cdot s + a \cdot s^2\right), \tag{2}$$

$$A_b = \Delta W_k - A_{rr} - A_d\,, \tag{3}$$

$$A_\tau = A_{rr} + A_d + A_b\,, \tag{4}$$

where A_{rr} – rolling resistance work, J;
c_{rr} – rolling resistance coefficient;
g – gravitational acceleration, m·s^{-2};
m – vehicle mass, kg;
A_d – air drag work, J;
$c_w{\cdot}A$ –air drag factor, m^2;
ρ_a– ambient air density, kg·m^{-3};
v_0 – vehicle speed at the start of constant acceleration section, m·s^{-1};
a – acceleration at the given section, m·s^{-2};
s – section length, m;
A_b – energy dissipated during braking, J;
ΔW_k – change in vehicle kinetic energy, J;
A_t – vehicle traction energy, J.

Conclusions have been made based on the modeling, targeted driving pattern measurements and obtained real life driving results.

Results and discussion

Results of the practical experiments for evaluating the energy requirement limits are shown in Fig. 4. The rapid acceleration and braking trials shown in Fig. 1 are marked with a legend "Fig. 1 cycle".

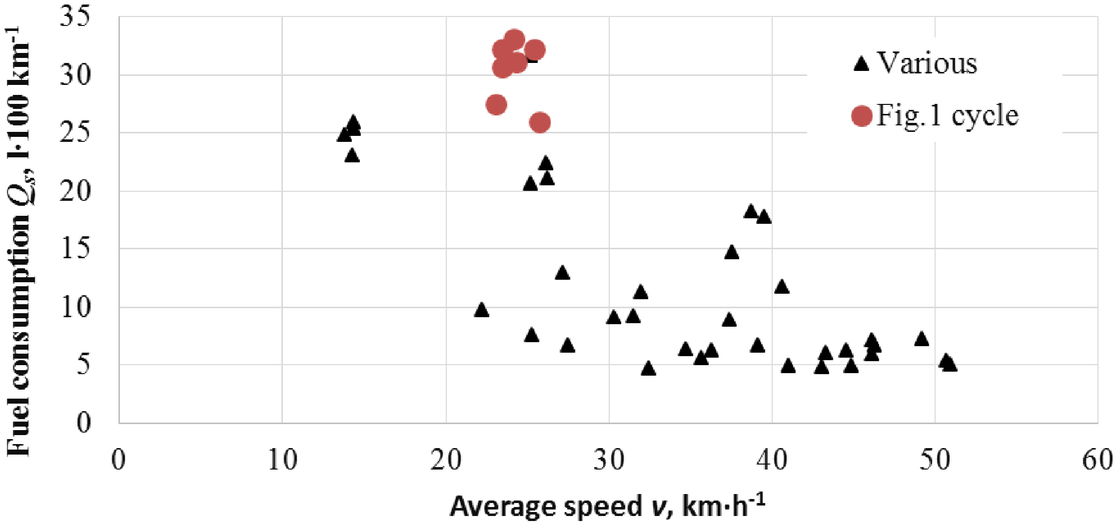

Fig. 4. **Fuel consumption for cyclic driving trials**

Driving the car with constant speed gives fuel consumption Q_s slightly below 5 l·100 km^{-1}. Fuel consumption for rapid acceleration and stoppage is even above 30 l·100 km^{-1}. The big difference is due to kinetic energy loss during braking in the stop and go traffic. To have quantitative evaluation of the energy limits needed for traffic with a rather low maximum speed limit 50 km·h^{-1}, the computer modeling results have been analyzed. The results are shown in Fig. 5.

For the researched vehicle with the selected acceleration and braking intensity almost 14 full single 0…50…0 cycles can be achieved. The practical experiments gave 11.5 cycles per km, but the maximum speed was above 50 and in total the stoppage time between the cycles was 17 s. The energy requirements for 13 full cycles per km were more than 5 times higher compared to just 1 cycle per km. And even one stop per km requires almost 50 % more energy than driving at a constant speed. Since there is no driving at constant speed, the average speed is half of the maximum speed. This is quite unlikely pattern of driving for a longer distance, but shows the limits and the necessity of trying to avoid accelerations that are immediately followed by rapid braking.

After acceleration allowing the vehicle to coast in neutral just to 45 km·h^{-1} reduces the number of cycles that can be made per km below six and lowers the energy demand more than twice. The highest average speed is achieved when the braking phase starts between 35 and 40 km·h^{-1} and the energy requirement is some 60 % above the constant speed value and just one fifth of the maximum value. Braking from speeds between 25 and 30 km·h^{-1}require just some 10 % of extra energy compared to urban constant speed, therefore, from this point avoiding to apply brakes does not save much energy.

Since the most energy is lost during braking, the highest traction work is reached for frequent stop and go events. The diagram shows how much energy can be wasted in unnecessary braking events with corresponding high fuel consumption. When compared to constant speed energies, even few stops per km give essential increase, which largely overwhelm the energy growth from the constant speed increase within the allowed limits.

The test drive shown in Fig. 2 gave the speed profile presented in Fig. 6. The total time of the test was 92 minutes, the maximum speed is slightly below 90 km·h^{-1}(the road stretch outside the city limits to and back from the airport). The last 14 minutes for a 2 km stretch show the morning rush traffic for vehicles going into the city.

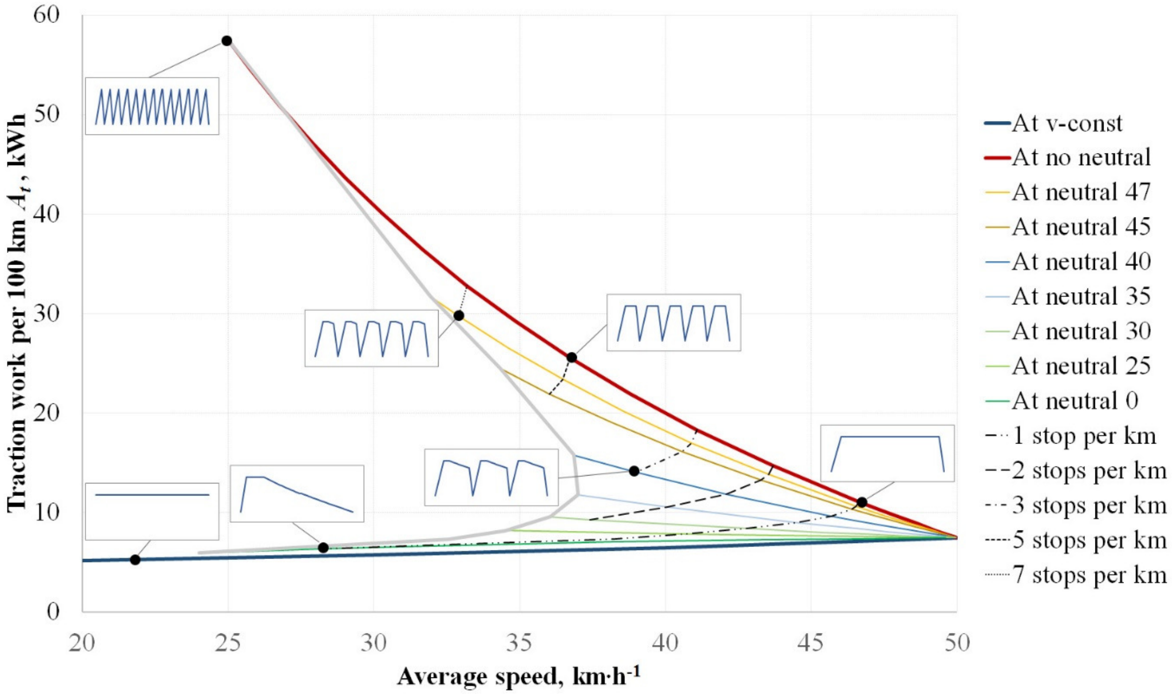

Fig. 5. **Computer modeling of traction energy at various cyclic driving patterns**

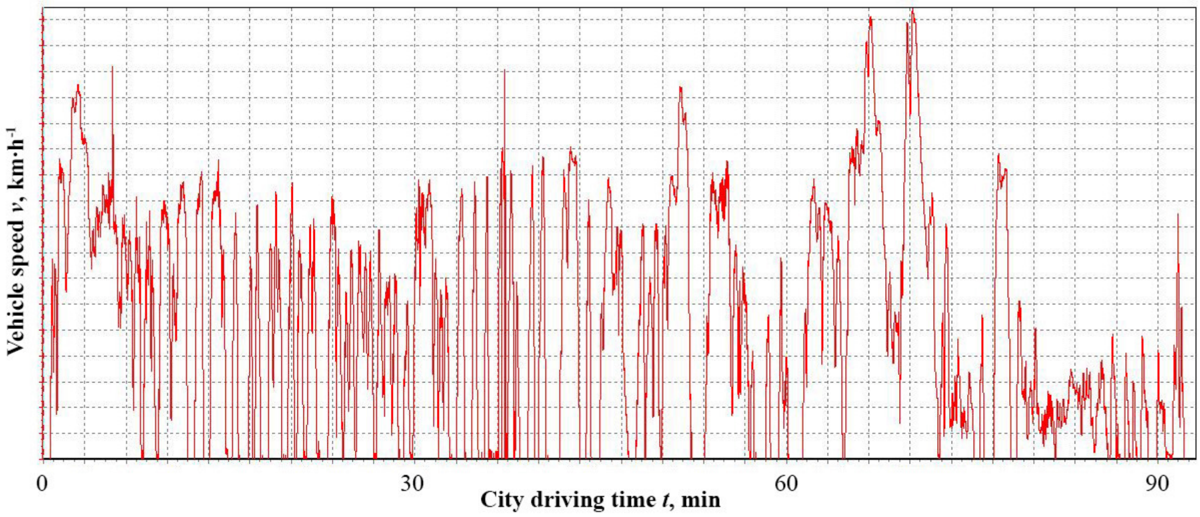

Fig. 6. **Riga city test drive speed profile (morning driving)**

For the test drive traction energies have been calculated and plotted versus the average speed in Fig. 7. To avoid the stop time influence on the average speed, all vehicle stops have been excluded from the calculation. Each point represents vehicle driving from standstill to standstill. All single cycles where maximum speed was above 60 km·h^{-1} have been excluded. For a reference two energy values for driving at constant speed are shown with dotted lines: driving at 100 km·h^{-1}and driving at 130 km·h^{-1}. Most of the samples fall within these constant speed limits, showing why city driving may require more fuel than constant driving at the allowed 90 km·h^{-1} speed. Two single points are added to the chart: energy and average speed for NEDC and the urban low speed part of the NEDC, known also as European Urban Driving Cycle. Fig. 7 shows that these values are well below the values obtained at the test drive in city traffic. This means that real city driving, including driving in Riga city, may be more energy demanding than driving by the standardized cycle. The fuel consumption measured for the test drive 8.2 l·100 km^{-1} is just above the value measured by NEDC but well below the given UDC value.

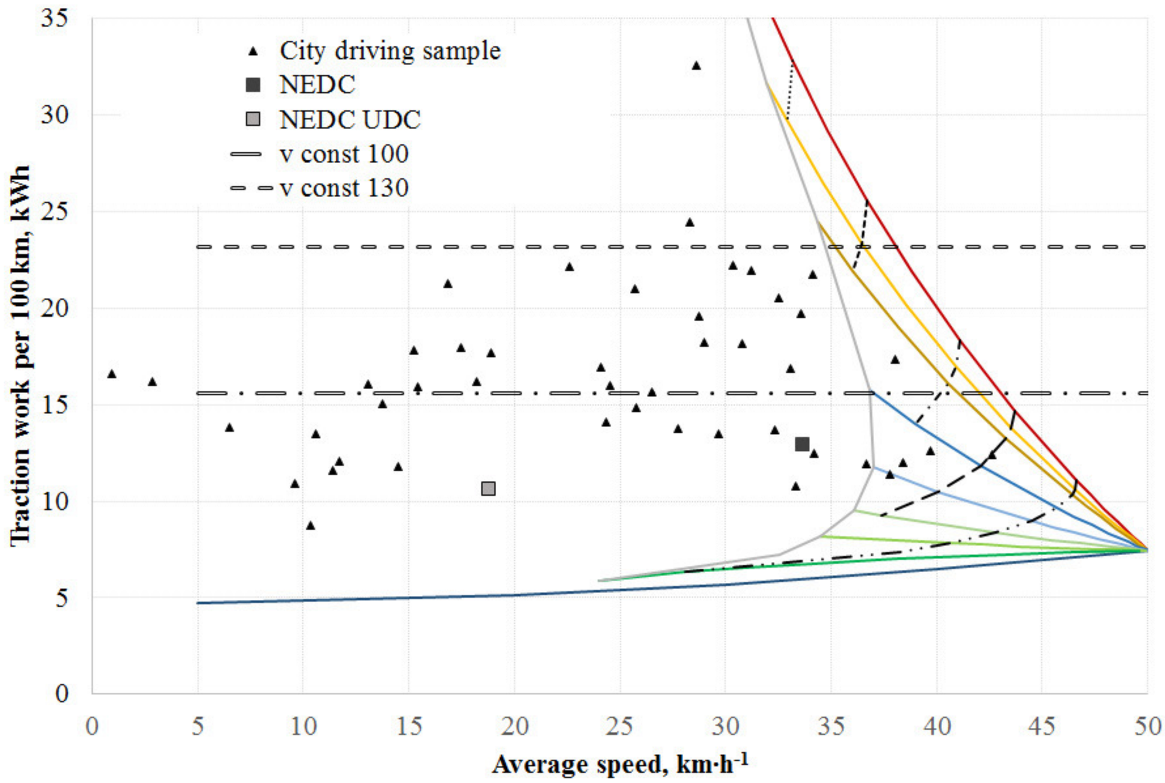

Fig. 7. **Traction energy for city driving test**

The traction energy analysis versus the average speed can be performed also for different maximum speeds using engine braking instead of coasting, various stoppage times, vehicle makes and combinations of the above. The traction energy analysis may give better visual understanding of energy usage than pie charts showing engine energy split.

Conclusions

1. Traction energy demand in urban driving for the same vehicle may considerably vary depending on the traffic situation and the driving pattern.
2. Braking in stop-and-go traffic increases the traction energy demand several times; coasting down (avoiding braking) to approx. 30 km·h^{-1} dramatically reduces the energy demand compared to continuous braking.
3. The traction energy plot versus the average speed gives an insight in the energy demand for different driving conditions and can be used for urban driving analysis.
4. The tests measurement in Riga showed interesting results for particular driving conditions but for more grounded conclusions additional research has to be conducted.

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