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SERBIAN SOCIETY OF AUTOMOTIVE ENGINEERS

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ACTUAL AND FUTURE EUROPEAN MOTOR VEHICLE EXHAUST EMISSIONS REGULATIONS

Stojan Petrović [1], Velimir Petrovic

UDC: 621.431.73;504.054

ABSTRACT: This paper presents an overview and analysis of European regulations related to the emissions of passenger and heavy-duty vehicles. After introduction, which summarizes the problem of motor vehicle exhaust emission, adopted European adopted emission standard are presented with special attention on newly introduced measurement of particle number concentration. Then, the emphasis has been put on world harmonization of emission control procedures and the establishment of the so-called Global Technical Regulation (GTR). In addition to the already adopted global harmonization of regulations and procedures for the assessment of emissions related to motorcycles (GTR 2), heavy vehicles (GTR 4) and non-road vehicles (GTR 11), special attention is paid to the new global regulation relating to the passenger cars (GTR 15). Finally, the paper analyzes the possibility of real driving emissions (RDE) measurement under consideration in EU and two possibilities are mentioned. Special attention is paid to the application of portable emission measurement system (PEMS) for testing vehicles particles emission under real driving conditions.

KEYWORDS: motor vehicle, exhaust emissions, regulations, world harmonization, real driving emission

POSTOJEĆI I BUDUĆI EVROPSKI PROPISI O IZDUVNOJ EMISIJI MOTORNIH VOZILA

REZIME: Ovaj rad daje pregled i analizu evropskih propisa evropskih propisa koji se odnose na izduvnu emisiju putničkih i teretnih motornih vozila. Nakon uvoda u kome se daju osnovne postavke problema emisije vozila, daje se kraći pregled postojećih usvojenih evropskih standarda o emisiji vozila sa posebnim osvrtom na novo usvojenu metodologiju merenja broja čestica. Nakon toga razmatra se problem svetske harmonizacije postupaka kontrole emisije, kao i stvaranje tzv. Globalne Tehničke Regulative (GTR). Pored već usvojenih globalnih harmonizovanih propisa i procedura o kontroli emisije motorcikala (GTR 2), teretnih vozila (GTR 4) i van-drumske mobilne mehanizacije (GTR 11), posebno se daje osvrt na novi globalni propis koji se odnosi na putnička vozila. Na kraju u radu se analizira postupak merenja emisije u realnim uslovima vožnje (RDE) koji je u razmatranju u EU i navode se dve mogućnosti za to. Posebna pažnja se posvećuje primeni prenosivih sistema za merenje emisije (PEMS) za ispitivanje emisije čestica u realnim uslovima vožnje.

KLJUČNE REČI: motorna vozila, izduvna emisija, zakonski propisi, svetska harmonizacija, globalna tehnička regulativa

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ACTUAL AND FUTURE EUROPEAN MOTOR VEHICLE EXHAUST EMISSIONS REGULATIONS

Stojan Petrović1PhD, Professor, Velimir Petrovic 2, PhD

UDC:621.431.73;504.054

INTRODUCTION

The mobility is one of the main characteristics of modern life. Comprehensive transport is precondition for intensive mobility, developed economy and normal human activities. Motor vehicle is one of the most important factors in transportation. However, sometimes it can be heard that transports sector, i.e. motor vehicles are the human environments enemy number one. Though this is unfair, in some cases it can be truth. But let us start from the beginning.

The invention of wheel and the creation of the first wheeled vehicle in the distant past improved man's mobility and caused a technical revolution with far-reaching consequences. Probably our distant ancestors who found it did not know how much trouble it will cause in the future. Actually, there were not much of problems for a long time in the past when the main vehicle propulsion was animal power. This vehicle was relatively slow, it could not even carry either a lot of people or a lot of goods, but it could not cause major traffic accidents or create major environmental problems. But when in the second half of the nineteenth century the first internal combustion engine was invented, and when it was incorporated into the vehicle, the situation has changed significantly. So created vehicle was significantly faster, could move to far distances in a short time to and carry more people and cargo.

The potential advantages of motor vehicles have rapidly increased the number of light and heavy vehicles. However, the increased number of vehicles has created several problems. One of the biggest problems is air pollution caused mainly by their exhaust gases. Road transport often appears as the most important source of urban pollutant emissions. In current decade, road transport is likely to remain a large contributor to air pollution, especially in urban areas. In current decade, road transport is likely to remain a large contributor to air pollution, especially in urban areas.

To prevent further pollution and eventually to reduce it, legislation on permissible emission of toxic components in the vehicle exhaust has been introduced.

EUROPEAN VEHICLE EMISSION REGULATIONS

First vehicle emission regulations were introduced in US and Japan at the beginning of second half of last century. Europe followed through UN Economic Commission for Europe where its administrative body WP.29 adopted Agreement 1958 on uniform technical prescriptions for wheeled vehicles, so called ECE Regulations. There is now 133 adopted ECE regulations and 7of them are directly related to exhaust emissions of motorcycles (ECE 40), mopeds (ECE 47), passenger cars and light commercial vehicles (ECE 15 and 83), heavy commercial vehicles (ECE 24 and 49) and non-road mobile machinery (ECE 96).

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The Agreement 1958 has currently more than fifty Contracting Parties and they are (with their ECE code) [1]: E1 GERMANY, E2 FRANCE, E3 ITALY, E4 NETHERLANDS, E5 SWEDEN, E6 BELGIUM, E7 HUNGARY, E8 CZECH REPUBLIC, E9 SPAIN, E10 SERBIA, E11 UNITED KINGDOM, E12 AUSTRIA, E13 LUXEMBOURG, E14 SWITZERLAND, E16 NORWAY, E17 FINLAND, E18 DENMARK, E19 ROMANIA, E20 POLAND, E21 PORTUGAL, E22 RUSSIAN FEDERATION, E23 GREECE, E24 IRELAND, E25 CROATIA, E26 SLOVENIA, E27 SLOVAKIA, E28 BELARUS, E29 ESTONIA, E31 BOSNIA & HERZEGOVINA, E32 LATVIA, E34 BULGARIA, E36 LITHUANIA, E37 TURKEY, E39 AZERBAIJAN, E40 THE F.Y.R. OF MACEDONIA, E42 EUROPEAN COMMUNITY, E43 JAPAN, E45 AUSTRALIA, E46 UKRAINE, E47 SOUTH AFRICA, E48 NEW ZEALAND, E49 CYPRUS, E50 MALTA, E51 REPUBLIC OF KOREA, E52 THAILAND, E53 MALAYSIA, E54 ALBANIA, E56 MONTENEGRO, E58 TUNISIA, E62 EGYPT. Serbia has very low code (E10) since it succeeded Yugoslavia who signed the agreement between first. USA did not sign the agreement, but they participate in the work of WP.29. Canada, China and India did not sign the agreement, but they participate in the work of WP.29 and they are applying several UN/ECE Regulations.

Main characteristics of 1958 Agreement (amended in October 1995) are [2]:

- o UN/ECE Regulations establish uniform provisions for mutually recognized type approval of vehicle systems, equipment and parts
- o UN/ECE Regulations are optional
- o UN/ECE Regulations become legal instruments only when incorporated into the national legislation
- o Parties are obliged to accept for marketing or registration products type approved by any Contracting Party to the same Regulation
- o Parties have privilege to type approve products if they have expertise
- o Administrative Departments and Technical Services designated by Contracting parties share information about type approvals
- o Administrative Department issuing type approval retains responsibility for conformity of the series production with the type approved

ECE Regulations on exhaust emissions define testing procedures, measurement methodology and permissible limits of pollutants. Appropriate EU Directives have accepted procedures and methodology from UN/ECE Regulations but the limits were tighten gradually from 1990 up to the present in the form of so-called Euro standards. These standards are then incorporated in appropriate ECE Regulations in the form of new amendments. EU Directives and UN/ECE Regulations for certain types of vehicle are practically identical.

THE EMISSION LIMITS FOR PASSENGER CAR

The emission limits for passenger cars from 1992 to 2014 are shown in Fig. 1. Euro 5 and 6 emission limits for conventional (multi point injection – MPI) gasoline engines are only with small reduction and do not require significant technological changes. The only novelty is that gasoline direct injection engines require particle emission measurement. However, diesel engine emission limits involve important changes. Particulate matter PM mass emission Euro 5 limits are extremely low, as well as Euro 6 emission limits for NOx. However, the important novelty is introduction of particle number emission limits.

			EU-1	EU-2	EU-3	EU-4	EU-5	EU-5+	EU-6	EU-6+
			1992	1996	2000	2005	2009	2011	2014	2017
Test Cycle			ECE 15.04	ECE 15.05	NEDC	NEDC	NEDC	NEDC	NEDC ? WLTP ?	
Positive Ignition Engines (Gasoline)	CO	mg/km	2720	2200	2300	1000	1000	1000	1000	
	HC	mg/km			200	100	100	100	100	
	HC + NOx	mg/km	970	500						
	NOx	mg/km			150	80	60	60	60	
	NMHC	mg/km					68	68	68	
	PM only GDI	mg/km					5	4,5	4,5	
	PN	#/km							6E12	6E11
Compression Ignition Engines (Diesel)	CO	mg/km	2720	1000	640	500	500	500	500	
	HC + NOx	mg/km	970	700	560	300	230	230	170	
	NOx	mg/km			500	250	180	180	80	
	PM	mg/km	140	80	50	25	5	4,5	4,5	
	PN	#/km						6E11	6E11	

no change | change | important

Figure 1 EU emission limits for passenger cars [3]

Actually, extremely low particulate matter mass emission is with high measurement error. Fig. 2 shows typical repeatability (obtained results in same laboratory) and reproducibility (obtained results in different laboratory) of heavy duty diesel engine particulate matter mass measurement [4, 5, 6]. Evidently, measurement method of particulate matter mass measurement should be improved. But it is concluded that measurement of PM mass concentration is not only important factor since in low PM mass emission can exists a high number of small particles. At the same time, health experts have concluded that small particles are more dangerous than great ones. Actually, big particles can be retained in the nose, but small particles go in the human lung, penetrate in the blood and then deposit in the brain or heart.

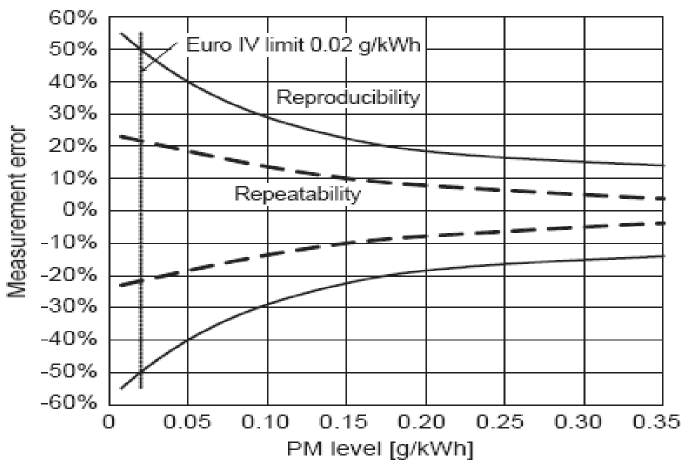

***Figure 2** The effect of low particulate matter emission*

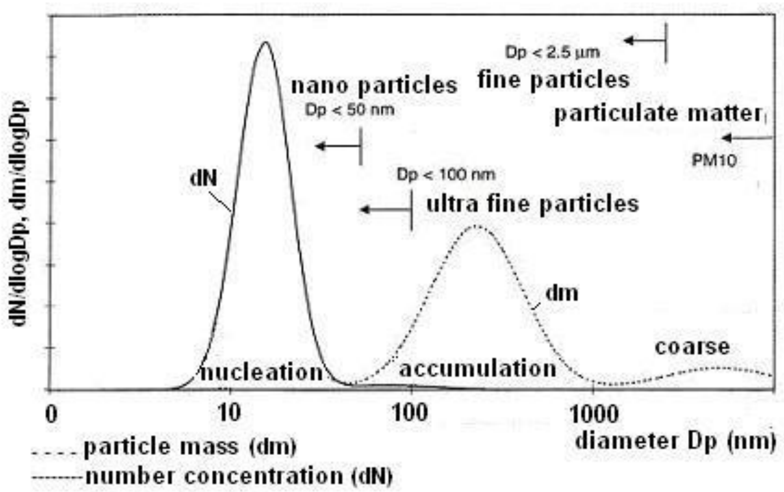

***Figure 3** Particle number and mass distributions*

Fig. 3 shows typical particle number (dN/dlogDp) and mass (dm/dlogDp) distribution in the function of particle diameter [6, 7]. Three typical phases of particle formation can be noticed. In the first phase are nano particles from nucleation phase. The second phase involves fine particles from accumulation phase and the third are coarse particles (which are eliminated in the modern diesel engines with high pressure injection, so their number is considerably low as well as mass). Total mass of emitted particles comes mainly from accumulation phase with fine particles smaller than 2.5 µm, but their number can be small (depending on applied technology and exhaust gas after treatment system). As concerns number concentration, nano particles are dominant. The composition of fine particles is mostly solid carbon and the composition of nano particles is mainly liquid compounds and volatile hydrocarbons. Particles from the first phase are the biggest problem. They are mostly unstable and almost without mass, but enormous by number. The correct measurement of their number concentration is not possible.

To solve the problem of particle number measurement, PMP group of UN/ECE/WP.29/GRPE has proposed approval methodology shown in Fig. 4 [6, 8]. According to this proposal standard CVS dilution tunnel should be used. The exhaust gas sample, taken from the tunnel, goes to the cyclone pre-classifier which remove particles bigger than about 2.5 microns. After dilution with hot air (PND1), sample is driven through heated evaporation tube HT (heated up to 150 C) where volatile components are removed. As the sample has to be cold at the entrance of particle counter, and to prevent condensation, the sample is again cold diluted (PND2) and then it is driven to particle number counter (PNC) where only number of solid particles is measured, which enables satisfactory repeatability and reproducibility. Condensation particle counter (CPC) is used as PNC device.

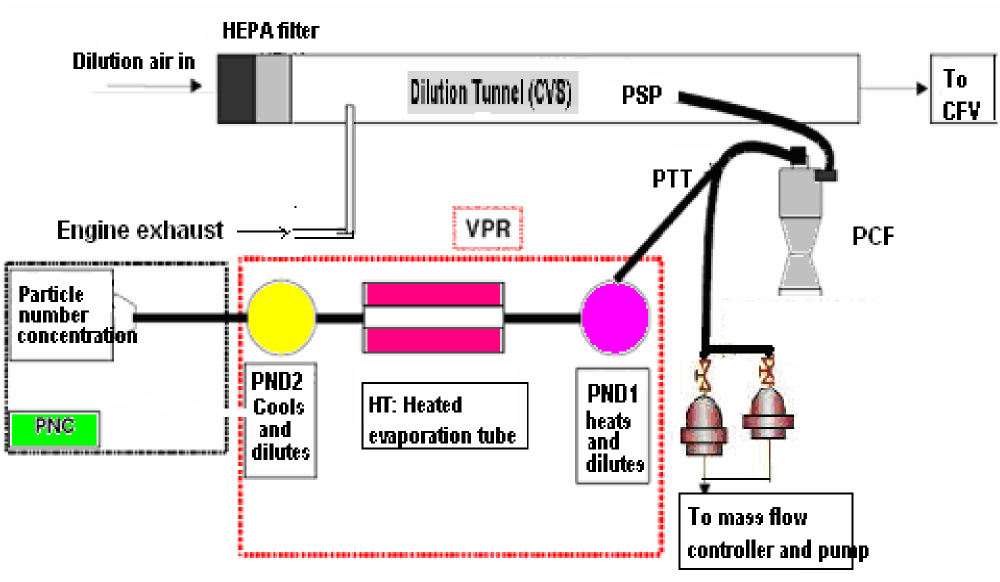

***Figure 4** Sheme of particle emission measurement*

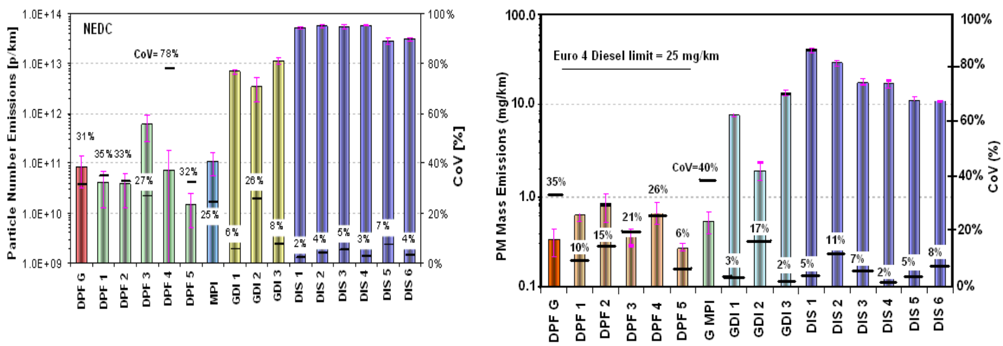

***Figure 5** Particulate mass (left) and particle number (right) emissions for vehicles with different engine technologies*

The results of particulate matter mass and particle number emissions of passenger cars with different engine technologies, obtained during Inter-laboratory Correlation Exercise (ILCE) to verify PMP proposed procedure, are shown in Fig. 5 [7, 9]. Particle mass emissions for all vehicles with particulate filter (DPF) are always very low: much bellows 1 mg/km. The particle mass emissions repeatability (coefficient of variations – CoV) of DPF diesel vehicles is very high and its average is about 20%. Mass particulate emission of multi point injection gasoline engines (G MPI) is at the same level with DPF engines and, also, its repeatability is very bad with high CoV (about 40%). The particle mass emission of direct injection gasoline engines (GDI) is almost ten times higher than the PM emission of DPF diesel engines, but the repeatability of test data is much better (CoV ranges from 2% to 17%). The particulate mass emissions of conventional Euro 4 diesel (DIS) engine (without particulate filter) is almost hundred times higher than emissions of DPF engines, but the results repeatability is much better with CoV mainly bellow 10.

Particle number emissions of diesel DPF vehicles were on level of gasoline engine with MPI injection. It can be expected that number emissions of these vehicles should be max. 10^{12} particles/km in NEDC test. Direct gasoline injection engine had ten times higher particles number concentration in comparison with diesel DPF and gasoline MPI engines. Their emissions is bellow 10^{13} particles/km. Diesel Euro 4 cars without DPF had hundred times higher particle number emissions than DPF vehicles. Their number emissions are bellow 10^{14} particles/km in NEDC test. Test results repeatability (CoV) is almost perfect for conventional diesel non-DPF vehicles and their CoV is mainly under 5%. However, the repeatability of DPF vehicles is much worst and their CoV was over 30%.

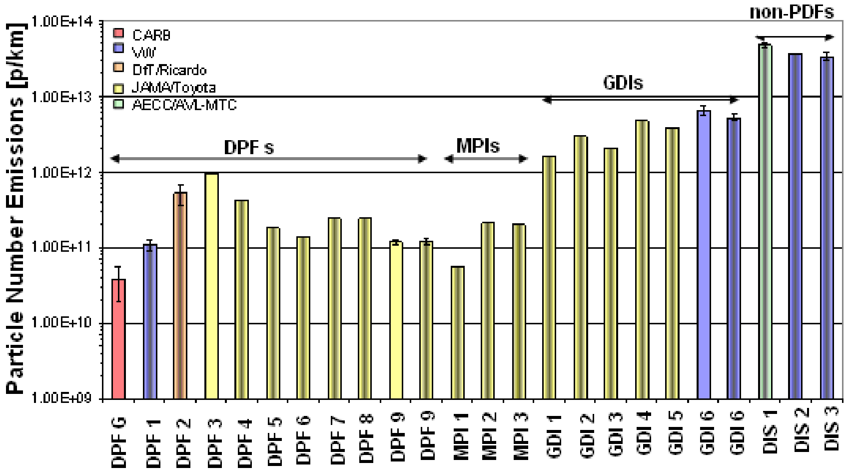

***Figure 6** Particle number emissions for vehicles tested outside PMP*

Fig. 6 shows some results of particle number emission measurements outside of PMP inter-laboratory correlation exercise in different laboratory and with different engine technologies, but using PMP measurement procedure in NEDC. The results are almost identical as in PMP testing. Particle number emission of DPF vehicles ranged from 1011 to 1012 p/km, for MPI gasoline engines it ranged from 5x1010 p/km to 5x1011 p/km, for GDI engines it was from 1012 to 10 13 p/km and for conventional diesel engines without DPF it ranged from 1013 to 1014 p/km [7, 10].

THE EMISSION LIMITS FOR HEAVY-DUTY ENGINES

The emission limits for heavy-duty engines from 1992 to 2014 are shown in Fig. 7. Actually Euro IV standards introduced very low limits for particulate mass emission (five times lower than Euro III) and not so strict limits for NOx. However, Euro VI standards reduced emission limits for NOx several times and particulate matters PM emission for more than double compared with Euro IV standards. At the same time Euro VI standard introduced particle number measurement with similar PMP procedure as for passenger cars with very low limits corresponding to the emission of diesel DPF engines. This procedure also includes counting of solid particle in engine exhaust.

Test cycles			I 1992	II 1996	III 2000	IV 2005	V 2008	VI 2013
Test cycles EU-I+II 13-Mode EU-III+IV ESC EU-VI WHSC	CO	g/kW-h	4,50	4,00	2,10	1,50	1,50	1,50
	THC	g/kW-h	1,10	1,10	0,66	0,46	0,46	0,13
	NMHC	g/kW-h						
	CH4	g/kW-h						
	NOx	g/kW-h	8,00	7,00	5,00	3,50	2,00	0,40
	PM	g/kW-h	3,60	0,15	0,10	0,02	0,02	0,01
	NH3	ppm				25	25	10
	PN	#/kWh						8 E11
	CO2, FC	g/kW-h						no
	NO2	g/kW-h						?
Test cycles EU-III+IV ETC EU-VI WHTC	CO	g/kW-h			5,40	4,00	4,00	4,00
	THC	g/kW-h						0,16
	NMHC	g/kW-h			0,78	0,55	0,55	
	CH4	g/kW-h			1,60	1,10	1,10	
	NOx	g/kW-h			5,00	3,50	2,00	0,46
	PM	g/kW-h			0,16	0,03	0,03	0,01
	NH3	ppm				25	25	10
	PN	#/kWh						6 E11
	CO2, FC	g/kW-h						no
	NO2	g/kW-h						?

Moderate Reduction (<30%) Large Reduction (>30%)

Figure 7 *Emission limits for heavy-duty engines* [3, 11, 12]

Some results of particles number emission measurement in different tests for a DPF 6 cylinder HD engine are shown in Fig. 8 [13]. The PMP system consists of a pre-classifier/cyclone sampling directly from the constant volume sampler (CVS) with a 2.5 μm size cut, a volatile particle remover (VPR) for volatile species control, and a CPC. The VPR includes an initial hot dilution (150◦C) stage, where the liquid volatile concentration is reduced, followed by a tube heated to 300◦C, where volatiles are evaporated, followed by a second diluter to prevent subsequent nucleation. Fig. 8 shows tailpipe particle number emissions from European (ETC), US (FTP) and Japanese (JE05) regulatory cycles, the World Harmonized Transient Cycle (WHTC) and the Non-road Transient Cycle (NRTC). For those cycles with cold- and hot-start portions, results are shown for the cold- and hot-start cycles separately. In addition results are shown for the hot-start WHTC with the 5, 10 and 20 minute soak periods. All tailpipe emissions measurements are the average of at least three tests. It is very interesting and important that all results are very similar and that the differences are very small.

WORLD HARMONIZATION OF TESTING PROCEDURE

Current legislations on exhaust emissions of motor vehicles are so strict that the further reduction of emission limits is impossible. At the same time, these reduced emissions are not accompanied by corresponding improvement in air quality. A reason for this is that the emission testing procedures, prescribed by existing legislations, do not correspond to the actual driving conditions. An additional problem is the lack of uniformity of vehicle emission control procedures in different regions of the world. Therefore, it is concluded that it is necessary to harmonize the emission testing procedures which should be adjust to the real driving conditions.

In 1994 the United States of America initiated and negotiated in cooperation with the EU and Japan in view of establishing a transparent process for improving global safety, decreasing of environmental pollution and consumption of energy through globally uniform technical regulations. Agreement on Global Technical Regulation (GTR) was concluded and opened for signature on 25 June 1998. The United States of America first signed the Agreement 1998 and it entered into force on 25 August for 8 Contracting Parties. Unfortunately U.S. of America has withdrawn sponsoring GTR in 2010. Also, it should be mentioned that in 2000, WP.29 becomes a Global Forum (March, 120th session) called World Forum for Harmonization of Vehicle Regulations [2, 15].

Global Technical Regulation (GTR) Agreement 1998 currently has 33 Contracting Parties (year of signature in bracket) [14]: AUSTRALIA (2008), AZERBAIJAN (2002), CANADA (1999), P. R. CHINA (2000), CYPRUS (2005), EUROPEAN UNION (1999), FINLAND (2001), FRANCE (1999), GERMANY (2000), HUNGARY (2001), INDIA (2006), ITALY (2000), JAPAN (1999), KAZAHSTAN (2011), R. KOREA (2000), LITHUANIA (2006), LUXEMBURG (2005), MALAYZIA (2006), R. MOLDOVA (2007), NETHERLANDS (2002), NEW ZEALAND (2001) NORWAY (2004), ROMANIA (2002), RUSSIAN FEDERAT. (2000), SLOVAKIA (2001), SOUTH AFRICA (2000), SPAIN (2000), SWEDEN (2002), TAJIKISTAN (2011), TURKEY (2001), TUNISIA (2007), UNITED KINGDOM (2000), U. S. OF AMERICA (1998). Serbia did not sign Agreement 1998.

There is now 15 adopted GTRs. Between them, 6 are on emission problems [15]:

GTR No. 2 - Motorcycles emission (adopted 2005)
GTR No. 4 – Heavy-duty engines emission (adopted 2006)
GTR No. 5 – On-board diagnostic systems (adopted 2006)
GTR No. 10 – Off-cycle emissions (adopted 2009)
GTR No. 11 – Non-road mobile machinery emissions (adopted 2009)
GTR No, 15 – Passenger cars emission (adopted 2014)

UN GTR NO. 2

Title of this GTR is “Measurement procedure for two-wheeled motorcycles equipped with a positive or compression ignition engine with regard to the emission of gaseous pollutants, CO2 emissions and fuel consumption” (ECE/TRANS/180/Add.2) [15]. It defines procedure and reference testing cycle: World-wide Motorcycle Transient Cycle (WMTC).

Reference cycle (WMTC) is not unique, but is composed of three parts, which are used depending on the class of motorcycle defined by engine volume and maximum speed of the vehicle. These three parts define different driving conditions and roads, as follows: part 1 simulates city driving, part 2 suburban and ordinary roads, and part 3 highway driving. The characteristics of classes are shown in Table 1. The scheme of WMTC is shown in Fig. 9.

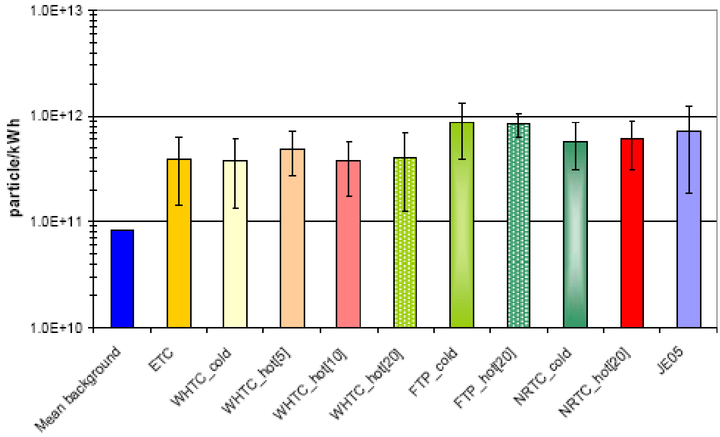

Figure 8 *Particle number emission of HD engine in different tests*

Table 1. *Classes of motorcycles*

Vehicle class	Characteristics	Cicle	Weighting factor
Class 1	Vh≤50 ccm, 50<Vmax<60 km/h or 50<Vh<150 ccm, Vmax≤50 km/h or Vh<150 ccm, Vmax<100 km/h	Part 1, cold	50 %
		Part 1, hot	50 %
Class 2	Vh<150 ccm, Vmax<100 km/h Vh≥150 ccm, Vmax<130 km/h	Part 1, cold	30 %
		Part 2, hot	70 %
Class 3	Vh≥150 ccm, Vmax≥130 km/h	Part 1, cold	25 %
		Part 2, hot	50 %
		Part 3, hot	25%

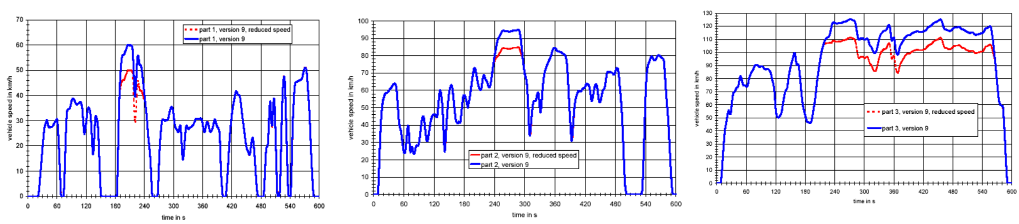

Figure 9 *Scheme of World-wide Motorcycle Transient Cycle (WMTC)*

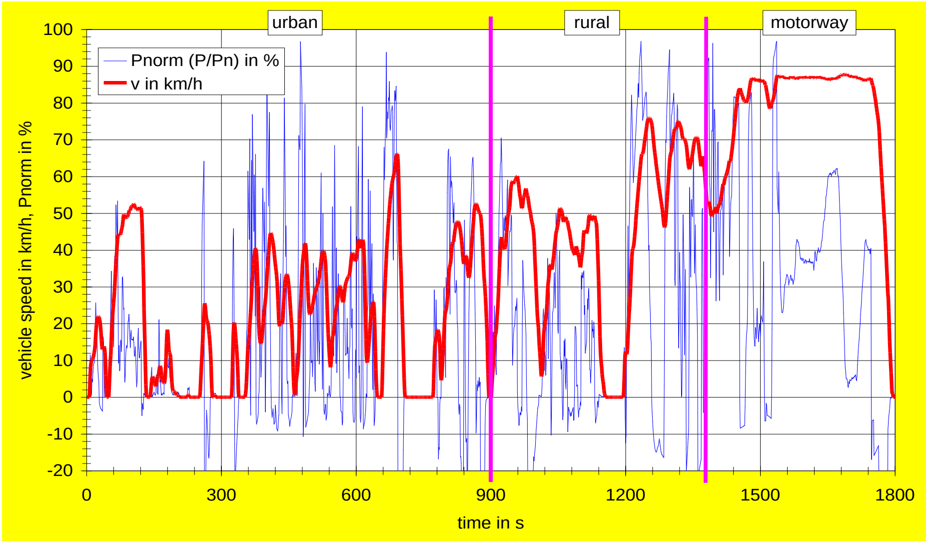

Figure 10 *Worldwide Transient Vehicle Cycle (WTVC)*

UN GTR NO. 4

The title of this GTR is "Test procedure for compression-ignition (C.I.) engines and positive-ignition (P.I.) engines fuelled with natural gas (NG) or liquefied petroleum gas (LPG) with regard to the emission of pollutants (WHDC)" (ECE/TRANS/180/Add.4) [15]. Worldwide harmonized Heavy Duty Certification (WHDC) is composed of three test cycles. The fundamental cycle is so-called Worldwide Transient Vehicle Cycle (WTVC) created from typical driving data recorded in USA, EU and Japan (Fig. 10) [16]. This cycle simulates driving in urban, suburban and road conditions with a constant change of load and speed. It is common for all vehicles. Since it is not possible to test a heavy vehicle on chassis dynamometer, this basic cycle serves for generation of control test for engine approval at dynamometer.

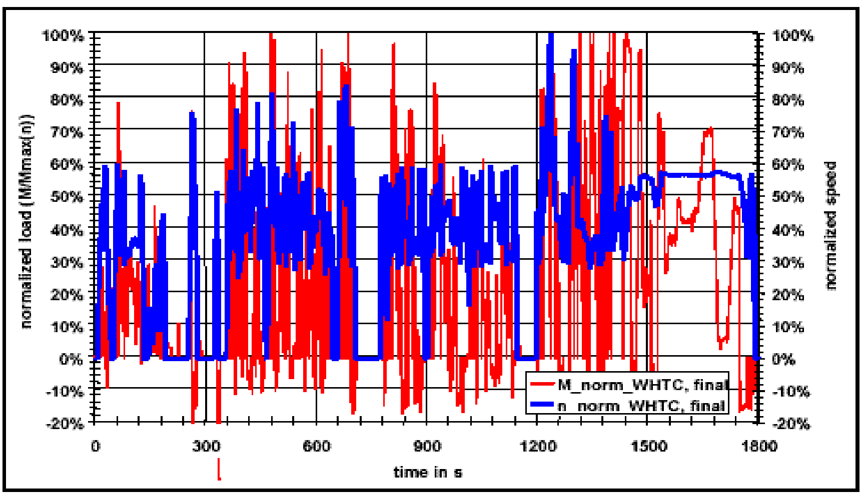

Figure 11 *Worldwide Harmonized Transient Cycle (WHTC)*

Worldwide Harmonized Transient Cycle (WHTC) uses normalized load and speed data from WTVC. Therefore, for each engine, test cycle should be first denormalized using real engine torque and power data. The normalized WHTC is shown in Fig. 11 [16]. WHTC is performed twice, as cold and hot test with soak period (5 or 20 s) between them. The results of cold and hot test are weighted as 5 or 14 % and 86 or 90 % respectively.

Using frequency distribution of load and speed of WTVC, the Worldwide Harmonized Steady-state Cycle (WHSC) is created using normalized load and speed data (Fig. 12). WHSC is quasi-stationary cycle called “ramped steady-state cycle”. Actually, transition from one regime to another is done through “ramp” – period of 20 s. Collection of data is not done mode by mode, as in old steady-state cycle, but continuously for whole cycle [16].

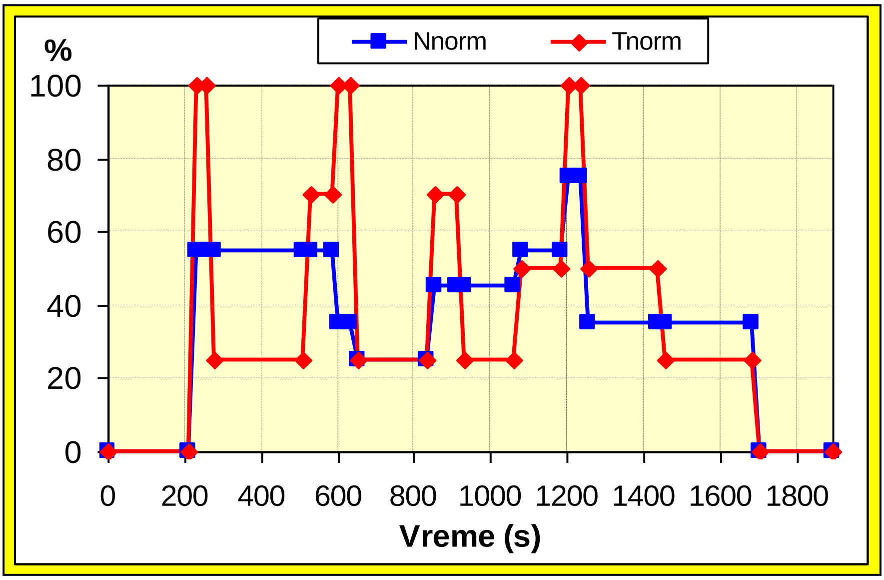

Figure 12 *Worldwide Harmonized Steady-state Cycle (WHTC)*

UN GTR NO. 5

The title of this GTR is “Technical requirements for on-board diagnostic systems (OBD) for road vehicles” (ECE/TRANS/180/Add.5) [15]. OBD system must detect a malfunction of either engine or after-treatment systems of exhaust gases. Also, he needs to show other information which should to be exchanged between the vehicle and power train. The proposal is based on technologies that are industrially available and in particular take due regard to the condition of the electronics in the period around 2008, as well as expected the latest technology of engines and exhaust after-treatment systems.

GTR proposal also defines the following items:

- Errors should be detected by the OBD system
- The information should provide OBD system and
- The process of approval OBD system

UN GTR NO. 10

The title of this GTR is “Off-cycle emissions (OCE)” (ECE/TRANS/180/Add.10) [15]. At the initiative of the United States, the discussion started on the problem of vehicle toxic emissions at engine regimes which are not covered by the procedure of light and heavy vehicles control testing. It was noted that the effects of improvements in vehicle emissions are not reflected in direct extent on reducing air pollution. One reason is that although the engine has satisfactory level of exhaust emission at approval testing, the increase of toxic emissions occurs in the use because the engine is not running the regimes in which the emissions was checked, and because the conditions of the engine in operation (temperature and ambient pressure) differ from those defined for the control test.

In the early considerations on this issue, in addition to the analysis of parameters and operating conditions that may affect the increased emission of the regimes which do not correspond to the control test, the effects of applying different tests on so called "off-cycle" emissions were analyzed and compared . It was pointed out that with regard to this problem, the advantage gives dynamic (transient) test WHTC that better covers the work area of the engine and harder it can be harder misused. This GTR is designed to be applicable to engines certified or type approved under the test procedures of GTR No. 4 on the Worldwide harmonized Heavy Duty Certification (WHDC).

The Off-Cycle Emissions (OCE) GTR includes two components. First, it contains provisions that prohibit the use of defeat strategies. Second, it introduces a methodology, termed the World-harmonized Not-to-Exceed (WNTE) methodology, for limiting off-cycle emissions. According to this GTR, Emission Limits are defined by next relation:

WNTE Emission Limit = WHTC Emission Limit + WNTE Component

where WNTE Component is:

for NOx: WNTE Component = 0.25 x EL + 0.1
for HC: WNTE Component = 0.15 x EL + 0.07
for CO: WNTE Component = 0.20 x EL + 0.2
for PM: WNTE Component = 0.25 x EL + 0.003

Off-cycle emissions can be checked in two ways:

- World-harmonized Not-To-Exceed in-use testing
- World-harmonized Not-To-Exceed laboratory testing

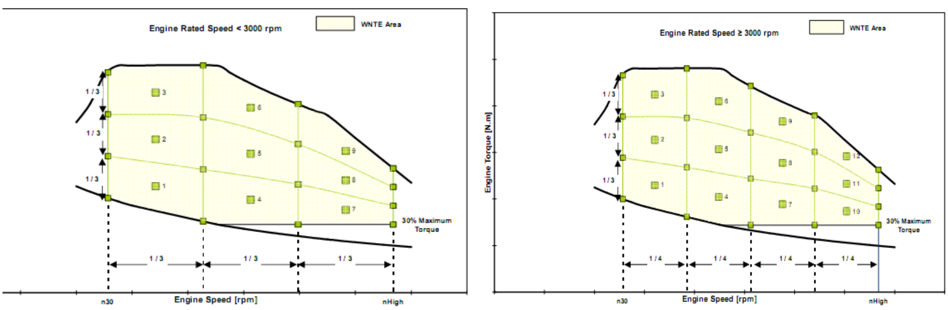

Figure 13 *WNTE control area grid for high (left) and super high (right) speed engines*

The GTR defines World-harmonized Not-To-Exceed (WNTE) laboratory testing. The specific mass emissions of regulated pollutants shall be determined on the basis of randomly defined test points distributed across the WNTE control area. All the test points shall be contained within 3 randomly selected grid cells imposed over the control area. The grid shall comprise of 9 cells for engines with a rated speed less than 3000 rpm and 12 cells for engines with a rated speed greater than or equal to 3000 rpm (Fig. 13).

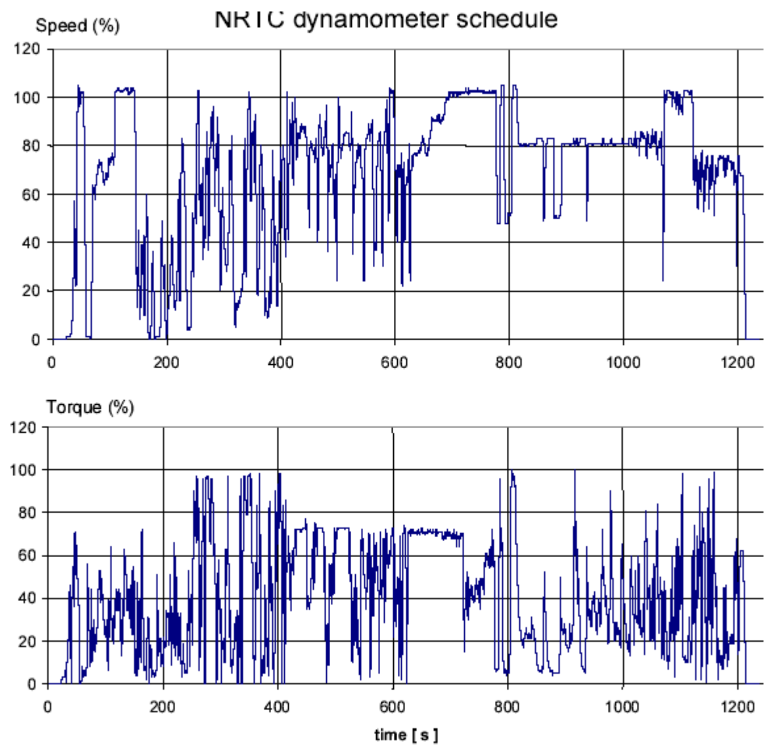

Figure 14 *NRDC driving schedule*

UN GTR NO. 11

The title is "Test procedure for compression-ignition engines to be installed in agricultural and forestry tractors and in non-road mobile machinery with regard to the emissions of pollutants by the engine" (ECE/TRANS/180/Add.11).

This regulation aims at providing a world-wide harmonized method to the determination of the emissions of pollutants of compression-ignition engines with a maximum power not smaller that 19 kW and not larger than 560 kW to be used in category T vehicles and in non-road mobile machinery.

The proposal is based on the EU directive that defines the dynamic cycle intended for emission testing of diesel engines for non-road vehicles (NRTC - Non Road Transient Cycle), which corresponds to the typical operating conditions of these engines. In fact it contains three 400 seconds sections with data of normalized values of engine torque and speed (Fig. 14). It is suggested that the NRTC cycle is performed twice: the first time with the start of cold engine (at room temperature) and the second time with a hot engine start (20 minutes after the first cycle). Then every cycle is weighted (first cycle with 10% and second with a 90%) to afford the reference emission per test.

UN GTR NO. 15

The title of this GTR is “Worldwide harmonized Light vehicle Test Procedures (WLTP)” (ECE/TRANS/180/Add.11) [15]. This global technical regulation (GTR) aims at providing a worldwide harmonized method to determine the levels of gaseous, particulate matter, particle number, CO2 emissions, fuel consumption, electric energy consumption and electric range from light-duty vehicles in a repeatable and reproducible manner designed to be representative of real world vehicle operation. The results will provide the basis for the regulation of these vehicles within regional type approval and certification procedures [17].

According to this GTR, all vehicles are classified in three classes:

- Class 1 vehicles have a power to unladen mass ratio (Pmr) ≤ 22 W/kg.
- Class 2 vehicles have a power to unladen mass ratio > 22 but ≤ 34 W/kg.
- Class 3 vehicles have a power to unladen mass ratio > 34 W/kg.

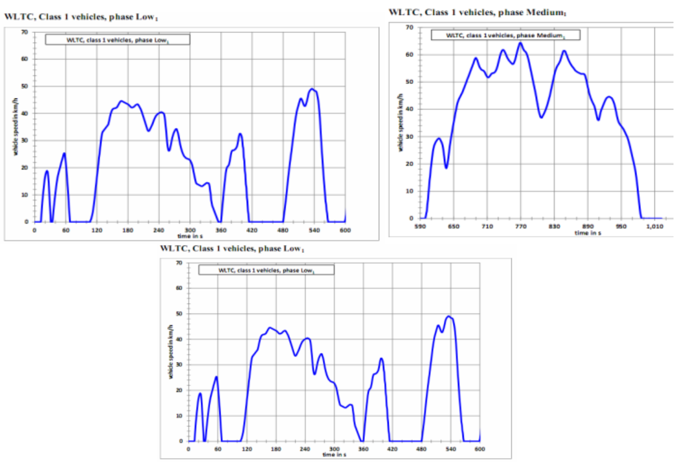

Figure 15 *Class 1 vehicles driving schedule*

A complete cycle for Class 1 vehicles (Fig.15) shall consist of a low phase (Low1), a medium phase (Medium1) and an additional low phase (Low1).

A complete cycle for Class 2 vehicles (Fig. 16) shall consist of a low phase (Low2), a medium phase (Medium2), a high phase (High2) and an extra high phase (Extra High2). At the option of the Contracting Party, the Extra High2 phase may be excluded.

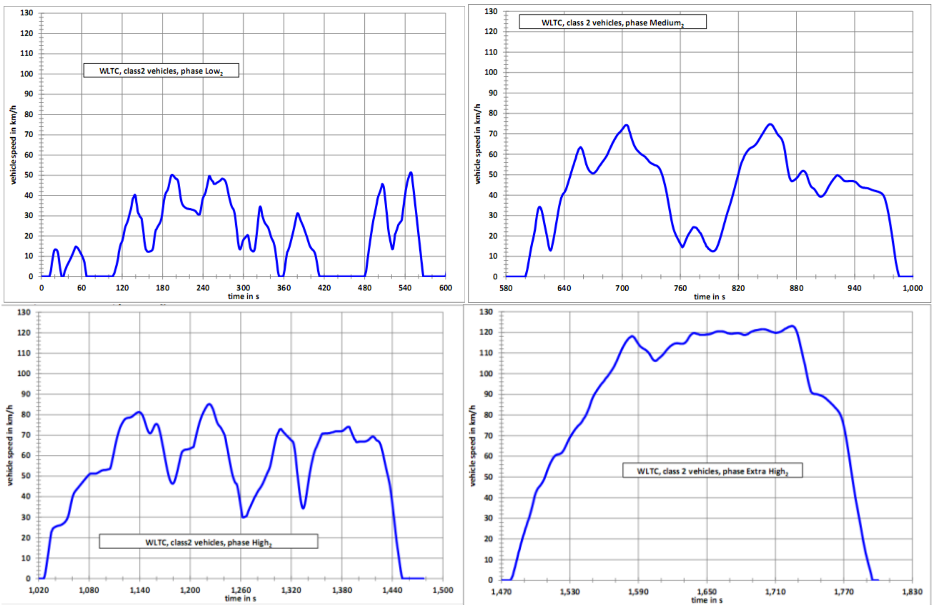

Figure 16 *Class 2 vehicles driving schedule*

Class 3 vehicles are mainly passenger cars. A complete cycle for Class 3 vehicles (Fig. 17) shall consist of a low phase (Low3) with driving speeds bellow 60 km/h, a medium phase (Medium3-1) with driving speeds bellow 80 km/h, a high phase (High3-1) with driving speeds bellow 100 km/h and an extra high phase (Extra High3) with max. speed ove 120 km/h. At the option of the Contracting Party, the Extra High3 phase may be excluded. Main characteristics of this cycle are: Time – 1800 s. Length – 23,26 km, Idle – 13 %, Vmax – 131,6 km/h, Vm – 46,3 km/h.

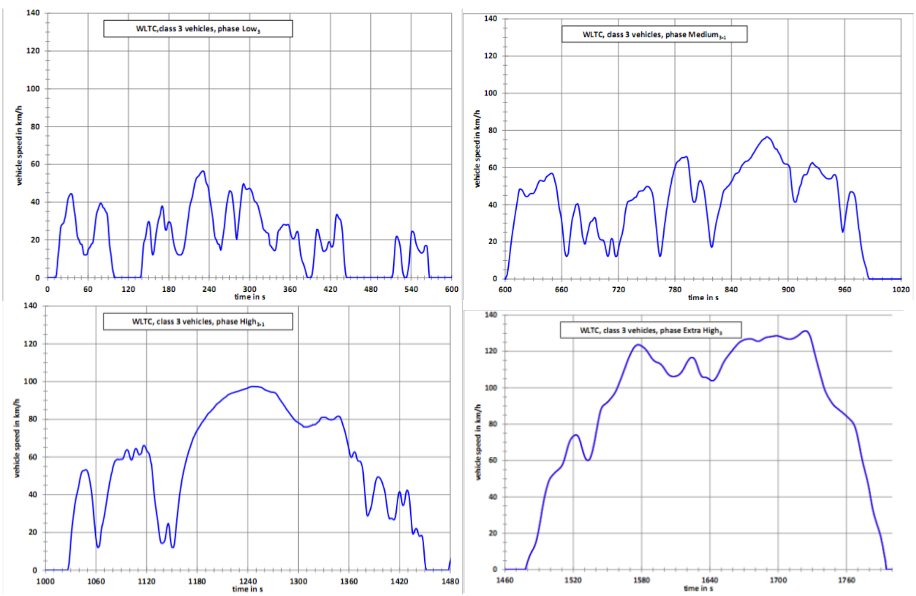

Figure 17 *Class 3 vehicles driving schedule*

REAL DRIVING EMISSIONS

Current tools and methods for evaluating pollutant emissions from road transport are mainly based on knowledge of specific vehicle emissions. Usually these emissions are measured on a test bench using test or driving cycles, or speed vs. time curves. The representativity of these cycles and their descriptive quality under real-world driving or vehicle operating conditions are thus of prime interest for the assessment of pollutant emissions and their evolution in an appropriate manner, in particular with newly developed technologies or fuels, the implementation of new regulations, or simply in function of the changes observed in trips and mobility [18].

The measurement of emissions in real-world driving situations will play an increasingly important role in vehicle and engine development in the future. New tehnologies for extra low engine emissions put new question: does emission testing in standard laboratory corresponds to real life emission of vehicle in-use? This is important since it has been noticed that vehicle emissions in real driving conditions is considerably higher than emissions measured in laboratory. The results collected previously on Euro 3-5 vehicles show that real-driving NOx emissions of light duty diesel vehicles did not change much over the last decade, despite the increased stringency of the limit values (Fig. 18) [19].

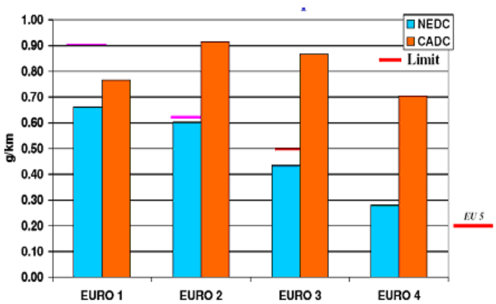

Figure 18 *Approval (blue) and real (red) emission results*

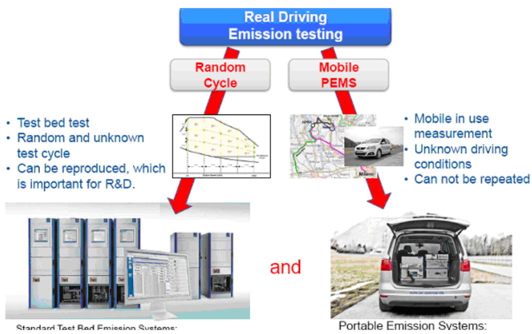

Figure 19 *Possible real emission measurement.*

There are two possibilities to check real emission level (Fig. 19):

- Random cycles in the test bed
- Mobile testing in the road

Main characteristic of test bed test is random and unknown test cycle schematically shown in Fig. 19 [3]. This cycle can be reproduced what can be important for research and development.

A main characteristic of mobile in use testing is unknown driving conditions. This cycle cannot be repeated.

Laboratory testing is preliminary proposed by UN GTR No. 10 on Off-Cycle Emissions. Mobile testing on road will be able after definition of Portable Emission Measurement Systems (PEMS).

PORTABLE EMISSION MEASUREMENT SYSTEM - PEMS

Portable Emissions Measurement Systems (PEMS) have been already included in U.S. legislation to control exhaust emissions of vehicles. EU supports for several years a project that should point to the most suitable methodology for measuring in-use emissions and its introduction in the regular procedure [18].

There is no problem with portable measurement of gaseous emission, but measurement particulate matter, especially particle number (PN) emission, is much bigger problem. Therefore, EU has undertaken PEMS project to validate potential instruments which can be used in mobile testing [6].

Potential instruments for particle number in-use measurement are shown in Table 2.

Table 2 *Potential portable emission instruments*

Company	**PEMS**
Control Systems	m-PSS
AVL	Micro Soot Sensor
Dekati	DMM 230
Dekati	ETaPS
Sensors	SEMTECH PPMD
Horiba	OBS-TRPM
Pegasor	PSS M
Matter Aerosol	Nanomet M3

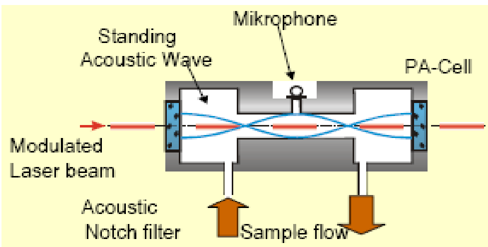

Figure 20 *Working principle of AVL MSS*

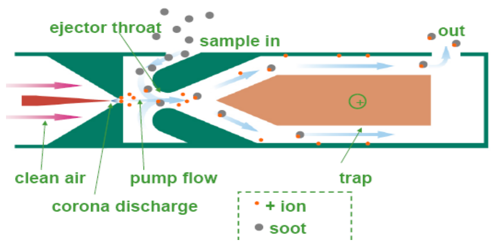

Figure 21 *Working principle of Pegasor PSS M*

More information on these instruments can be found in literature [6, 20, 21]. Only two of them will be shortly presented here just to have certain idea how they work.

The AVL Micro Soot Sensor (MSS) [22] is a system for continuous measurement of soot (not total PM) concentration in diluted exhaust from IC engines using The photoacoustic measuring principle. Fig. 20 shows its working principle. Highly absorbent soot particles is irradiated with modulated light. The periodic warming and cooling and the thus-resultant expansion and contraction of the carrier gas can be viewed as a sound wave and detected with microphones. Clean air does not produce a signal. With soot-laden air or exhaust gas, the signal increases proportionately with the concentration of soot in the measured volume.

Pegasor Particle Sensor (PPS) very compact and small instrument, which does not need special dilution (Fig. 21) [23, 24]. It uses raw exhaust gas and can be installed near to the exhaust pipe in the vehicle or at the test bench. At the entrance of sensor active part, fresh clean air is ionized by ~2 kV high voltage discharge at platinum corona needle. Positive ions are pushed through ejector nozzle which generates under pressure for the suction of sample gas with particles. After the ejector, turbulent mixing ensures a good connections between ions and particles and deposit of certain quantity of ion on particle surface. Positive free ions (not deposited on particles) are removed from sample flow by positive trap voltage from central electrode. The generated electrical field pushes free ions towards the wall of sensor's body where they are collected and only ionized particles leave the sensor [6]. An electrometer measures the difference between charge before (sample in) and after (sample out) faraday cup. This difference is proportional to the quantity of particles (total mass or number) in exhaust sample.

EU project on PEMS is still in active phase and different instruments are under investigation and comparison. Final decision on emission in-use testing should be done by 2017. PEMS will be introduced in Euro 6+ standard probably in the form of conformity of production check. The usage of most advanced technology makes it possible to reduce negative environmental effects of automobile and mobile machinery to minimum.

CONCLUSIONS

Permissible emission levels defined by existing standards are so severe that further reduction is practically impossible. Special problem is the inclusion of particle number limits for diesel engine and direct injection gasoline engine emission certifications.

Further reduction of air pollution by motor vehicle will be done by the improvement of testing procedure which should correspond to the real driving conditions. Global Technical Regulations enable World harmonization of vehicle regulations and creation of uniform provisions for certification testing procedure.

Real driving emission testing is under consideration and it will be included in emission certification procedure after definition of portable emission measurement systems.

REFERENCES

[1] Status of the Agreement, of the annexed UN Regulations and of amendments thereto, Revision 22, ECE/TRANS/WP.29/343/Rev.22, United Nations, Economic and Social Council, Geneva, 2014

[2] World Forum for Harmonization of vehicle regulations (WP.29): How It Works, How to Join It, ECE/TRANS/NONE/2012/1, United Nations, 2012.

[3] Engeljehringer K., AVL Emission Testing: Overview and Trends in Worldwide Emission Legislations, AVL List GmbH, Graz, 2013.

[4] - , Programme on Fine Particulate Emissions from Passenger Cars, ACEA, part I-II, Brussels, 2003.

[5] Petrović V., An Approach on the Investigation of Diesel Engine Particulate Emission (in Serbian), M. Sc. thesis, Faculty of Mechanical Engineering, University of Belgrade, Belgrade, 2006

[6] Petrovic V., Jankovic S., Tomic M., Jovanovic Z, Kneževic D., The Possibilities for Measurement and Characterization of Diesel Engine Fine Particles – A Review, THERMAL SCIENCE, Year 2011, Vol. 15, No. 4, pp. 915-938.

[7] Petrović, V. S., Particulate Matters from Diesel Engine Exhaust Emission, Thermal Science, 12 (2008), 2, pp. 183-198

[8] -, Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements, E/ECE/TRANS/505/Rev.1/Add.82/Rev.4, UN/ECE, 2011.

[9] -, Inter-Laboratory Correlation Exercise: Framework and Laboratory Guide, UN-GRPE PMP, Phase 3, Informal document no. GRPE-PMP-14-1, 2005

[10] -, Compilation of Existing Particle Number Data from outside PMP Inter-Laboratory Correlation Exercise (ILCE), GRPE-55-16, 2008

[11] Jörgl H., Particle Number Measurement – from ECE-R83 to ECE-R49, AVL List GmbH, from *www.testing-expo.com/europe/10txeu_conf/pdfs/day_2/340_wednesday_avl_joergl , 2010.*
[12] Petrovic V., Popovic V., Grozdanic B., Bracanovic Z., Jankovic S., A New Method For Particle Type Approval Testing For Heavy Duty Diesel Engine, Proceedings DEMI 2011, Banja Luka, 2011.

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ENVIRONMENTAL PROTECTION IN AUTOMOTIVE INDUSTRY

Dušan Gruden [1]

UDC: 504.054;67.017

ABSTRACT: For people from ancient times, the world consisted of four elements: air, water, earth and fire. And, although a modern man knows more than 110 chemical elements, his activities in the field of environmental protection are concentrated precisely on these four elements. Further human survival on this planet depends more and more on how much humans care about these elements and their existing reserves.

In the early 1970s, after nearly a hundred years of vehicle development, the vehicle's "eco-development" had started in order to reduce or completely eliminate the negative impact of vehicles on environment. Environmental protection and efficient use of the existing reserves of energy sources and raw materials are in the spotlight of the modern car development for decades and are deeply instilled in overall development of cars. Life cycle assessment, which is carried out with increasing precision, will contribute with new knowledge on possibility for further improvement of the car's environmental characteristics on its whole journey, from obtaining raw materials for its construction to recycling of end of life vehicles, "from the cradle to the grave".

KEY WORDS: automotive industry, environmental protection, emission reduction, life cycle assessment

ZAŠTITA ŽIVOTNE SREDINE U AUTOMOBILSKOJ INDUSTRIJI

REZIME: Još od davnih vremena za čoveka svet su činila četiri elementa: vazduh, voda, zemlja i vatra. Iako savremen čovek poznaje više od 110 hemijskih elemenata, njegove aktivnosti u oblasti zaštite životne sredine su usmerene na samo ova četiri elementa. Dalji opstanak čoveka na planeti zavisi sve više i više od odnosa čoveka prema ovim elementima i od njihovih rezervi.

Ranih 1970-tih godina, posle skoro sto godina od početka razvoja vozila, ekološki razvoj vozila je počeo kako bi se smanjila ili potpuno eliminisao negativan uticaj vozila na okruženje. Zaštita životne sredine i efikasno korišćenje postojećih rezervi izvora energije i sirovina su u fokusu razvoja savremenih vozila decenijama unazad i jako su implementirani u celokupni razvoj vozila. Procena životnog ciklusa, koja se realizuje sa sve većim preciznošću doprineće novim znanjima poboljšanju razvoja karakteristika automobile u odnosu na okruženje u celokupnom ciklusu, od nabavke sirovina za proizvodnju do reciklaže na kraju životnog ciklusa vozila "od kolevke do groba".

KLJUČNE REČI: automobilska industrija, zaštita životne sredine, smanjenje emisije, procena životnog ciklusa

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ENVIRONMENTAL PROTECTION IN AUTOMOTIVE INDUSTRY

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INTRODUCTION

Scientists claim that 1.000 billion (1012) galaxies exist in continuously expanding cosmos. One of these galaxies, "The Milky Way", contains 100 trillion (1020) stars. Among this infinitely large number of heavenly bodies, there is Earth, the planet we live on. Oxygen content of 21% in Earth's atmosphere, ¾ of Earth's surface under water and the difference between maximal and minimal temperatures on Earth's surface atmosphere amounting to 100°C (from -50°C to +50°C), have enabled life on Earth as we know it.

Despite the conviction of men, that we are very developed civilization, with almost unlimited possibilities of technology, man has not been able to prove that there is any other life in the rest of the universe. In other words, we are on our own in the infinite space. Planet Earth, with its many different forms of life, the rarity of the cosmos, must be preserved. That is primary obligation of the mankind, with all its possibilities.

For people from the ancient times, the world consisted of four elements: air, water, earth and fire. Although a modern man of the 21st century knows over 110 chemical elements, activities in contemporary environmental protection are focused precisely on these four elements, because all living beings on this planet need air, water and land for their existence. Clean air and clean water are prerequisites for living.

Prometheus was punished by the gods, because he allowed the people the use of fire, which had previously been the exclusive privilege of the gods. Mastering and using fire are the fundamental events that have provided people with evolutionary path of development, up to modern homo sapiens.

Despite the progress of modern man, one thing has not changed. In today's world, the four ancient elements are also of great importance. The further fate of the planet is becoming increasingly dependent on the kind of care we give to these elements and their remaining reserve. The four ancient elements must be protected and preserved:

Air: by continuing the reduction of exhaust emissions.

Water: by protecting it from the impurities and harmful sediment.

Earth: by reducing the amount of disposed waste and by rational use of its remaining reserves.

Fire: by better understanding of combustion process in engines and other technical processes and by increasing their efficiency.

Increase of the standard of living for many people has been achieved for the first time in the last century without the exploitation of other people, by using the technics and by exploitation of natural resources.

"Acid rain", "ozone hole", "forest decay" and "climate catastrophe", despite the excessive dimensions in which they are presented to the public, are still the warning signals that should not be ignored, because the over-exploited nature can perform its revolution, as well as over-exploited man. Only, by revolution of nature, all problems of mankind would have been irrevocably settled, once and for all.

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Is there a possible way out of this situation? Can we find solutions that will save the lives of all beings on this planet and allow further development of mankind? A huge moral responsibility for finding the answer to this question is laid upon us, the engineers.

Our technology is based on physical laws - the laws of nature. We just have to learn to use these laws in the technical products not against, but in cooperation and in accordance with nature. This is the one of the main challenges today. In order to survive, we must learn the motto: "A man and technology in harmony with nature".

VEHICLE AND HUMAN ENVIRONMENT

Motivated by his natural instincts: altius, citius, cellerius (higher, faster, further), a man was trying to increase the speed of his movements from his beginnings, in order to increase his mobility. Since the beginning of the so-called "Industrial Revolution", which began with the invention of the steam engine in the late 18th century, the image of nature is has changed significantly. The influence of man was particularly obvious in the crowded populated regions, where many plant and animal species were gone forever. Thus, the industrial revolution led to environmental disasters in many places.

With the invention of motorized vehicles in the late 19th century, men were provided with means to quickly and easily get to desired destination at any time. The vehicle was one of the inventions that have greatly contributed to the high standards of modern people and has become an inseparable part of modern society and of the economic system. Over 800 million passenger vehicles worldwide, over 99% of them driven by IC engines, are compelling evidence of need and desire for the vehicle.

Each year, about 70 million vehicles are produced the world (Fig. 1)

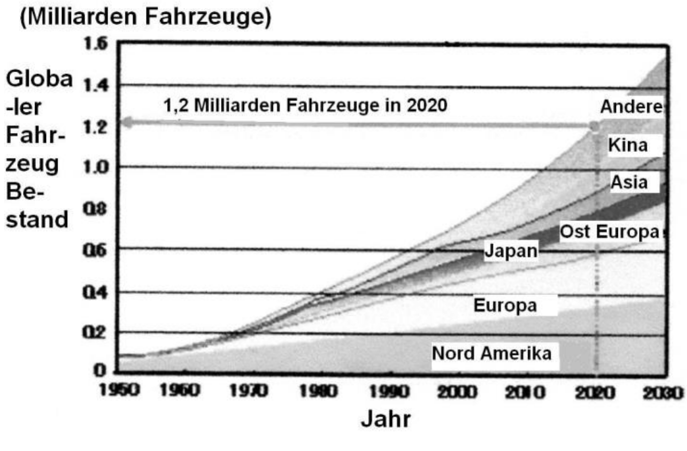


Figure 1 Vehicle manufacturing worldwide

This mass motorization has become a problem, because motorized traffic has become an important source of various impacts on the environment. It is one of the largest consumers of energy and a major source of unwanted exhaust emissions.

During the last decades, knowledge has been crystallized that the impact of vehicles on environment can be divided into:

Local impact: mainly in populated areas - emissions of carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NOx), particulate matter (soot, PM), noise and the like.

Regional impact: like "acid rains", "ozone smog", "forest decay", as well as the growing waste landfills and pollution of water and soil.

Global impact: usually registered in discussions on climate change, global warming, "ozone hole" and excessive exploitation of natural resources of energy, raw materials and food.

Concern about the impact of human activity on nature is not a new phenomenon or a new feature of the modern man. There is a new dimension of the efforts made to protect the environment.

In the early 1970s, after nearly a hundred years of vehicle development, the vehicle’s “eco-development” had started in order to reduce the negative impact of vehicles on nature and environment. The last third of the previous century will go into history as the phase of significant increase in responsibility of all industries in protecting the environment.

Although there has been much talk about air pollution in public, it took several decades before the European experts agreed on air quality that is required for a healthy life of humans, animals and plants. In the USA, the National Ambient Air Quality Standards (NAAQS) were adopted already in 1970 and were revised in 1985. European air quality standards were introduced at the beginning of this century (in 2005) and revised in 2010 (Fig. 2).

Pollutant	EU – AQFD Daughter Directives	USA
1. SO_2	μgm^3	μgm^3
1 hour mean	350 - not to be exceeded more than 24 times per calendar year (as of 1.1.2005)	–
3 hour mean	–	1310 – not to be exceeded more than once per year
24 hour mean	125 - not to be exceeded more than 3 times per calendar year	365 - not to be exceeded more than once per year
Annual mean	20 - annual and winter mean for protection of ecosystem	79
2. NO_x	μgm^3	μgm^3
1 hour mean	200 - not to be exceeded more than 8 times per calendar year (as of 1.1.2010)	–
Daily average of 1 hour	–	–
Annual mean	40	100
3. PM 2.5		μgm^3
24 hour average	–	65 μgm^3 - the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area
Annual average	–	15 μgm^3 the 3-year average of the annual arithmetic mean PM2.5 concentrations from single or multiple community-oriented monitors
4. PM 10	μgm^3	μgm^3
Hourly	–	–
24 hr mean	50 - not to be exceeded more than 35 times a calendar year (as of 1.1.2005)	150 μgm^3 - not to be exceeded more than once per year
Annual mean	40	50 μgm^3 expected annual arithmetic mean PM10 concentration at each monitor within an area
5. Lead	μgm^3	μgm^3
Annual	0,5 (as of 1.1.2005 or 1.1.2010 in immediate vicinity of specific sources situated on sites contaminated by decades of industrial activities)	–
Quarterly average	–	1.5 μgm^3

Comparison of the EU & US AQ Standards & Planning Requirements / 15

Figure 2 Air quality standards in the EU and the USA

Although modern vehicles are far better in terms of environmental characteristics than their predecessors from 30 or 20 years ago, they are still far from satisfactory, in public opinion.

Reduction of emission of carbon dioxide (CO2) and other emissions that are considered the cause of climate change is at the centre of the current environmental policy. Reduction of harmful exhaust emissions, fuel consumption and CO2 emissions follows the development of vehicle and its power unit - IC engine for decades.

ENVIRONMENTAL LAWS FOR AUTOMOTIVE INDUSTRY

Protection of the environment was declared as objective of national priority in many industrially developed countries. It stands as an equal category with classic objectives such as the preservation of peace, employment, economic growth and monetary stability

As the first measure, the legislation introduced the two categories of limit values for harmful air components.

The first category relates to the air quality at the workplace. In the European Union (EU), so called "Binding Limit Values" are valid, which are mandatory for all EU member states. Several hundred substances are included on this list (Regulation 67/548/EWG or EC 2008/1272 - Regulation on classification, labelling and packaging of substances and mixtures). This list replaces the former list of Maximum concentrations at the workplace (MAK).

The second category relates to the quality of the outer air. EU directives on “Ambient air quality and cleaner air for Europe” (2008/50/EC) and “National emissions ceilings for certain pollutants” (2001/81/EC - NEC Directive) provide immission limit values for a number of substances that occur frequently and can be harmful to health. Since January 1st, 2010, these limits may not be exceeded (Table 1).

Table 1 Immission Limits for individual components in the EU and proposal of the World Health Organization (WHO)

	2008/50/EC	WHO	
Carbon monoxide (CO), mg/m3	10	10	8h mean value
Nitrogen oxide (NO2), µg/m3	40	40	annual mean
Particles PM10, µg/m3	25	20	annual mean
Particles PM2,5 , µg/m3	25	10	annual mean
Ozone (O3), µg/m3	120	100	8h mean value
Benzene (C6H6), µg/m3	5	5	annual mean
Led (Pb), µg/m3	0,5	0,5	annual mean
Sulphur dioxide (SO2), µg/m3	50	20	annual mean

Further legislation limit the noise exposure (Regulation 86/188 / EEC - Protection of workers from exposure to noise at work) not only at the workplace, but also in everyday life (2003/10/EC - The minimum health and safety requirements (noise)).

Legislations regarding environmental protection guarantee the certainty that the prescribed imission values would be fulfilled.

Since the beginning of the 19th century, when first negative impacts of industrial production on nature were noticed, the number of regulations regarding environmental protection has been constantly increasing. Meanwhile, so many regulations have been created, that even the experts who deal with them, find it difficult to follow the development in this area.

REGULATIONS IMPORTANT FOR AUTOMOTIVE PRODUCTION

An important moment in European legislation in the field of environmental protection is the adoption of directive on Integrated pollution prevention and control (96/61/EC - IPPC).

Anyone who develops, produce, processes and sells products, carries a responsibility to meet all the standards of environmental protection.

The enforcement of the directive 2010/75/EC (IED - Industrial Emission Directive) is at the centre of activities, and it requires, among other things, the description of the current situation in emissions of all environmentally relevant production processes.

Water protection is regulated by laws, regulations and ordinances. In year 2000, the EU adopted a directive 2000/60/EC - Water Framework Directive on quality of wastewater.

European directive 75/442/EC - Waste Framework Directive (WFD) of 15 January 1975 has been the basis of European policy towards waste since January 15th, 1975. Since 2008, it regulates the waste treatment of industrial plants (2008/98/EC). Directive 91/156/EC (Directive on hazardous waste) defines as waste all which cannot be defined as a product.

Law on Chemicals should protect the environment from harmful effects of toxic substances. European directive REACH (Registration Evaluation and Authorization of Chemicals, 1907/2006/EC), which has been in force since 2005, provides strict control over those substances which may have a negative impact on health and environment. Since November 2011, the Law on classification of chemicals (1272/2008 / EC) has been in effect. This law and REACH regulation are the basis for safe use of chemicals in production.

Regulation on information related to environmental protection (2003/4/EC, Public access to environmental information) should facilitate a public access to information about the state of water, air, noise, soil and flora and fauna in the vicinity of industrial plants.

Regulations important for vehicle homologation

The technical development of vehicles today is unthinkable without taking into account the strict regulations. Fig. 3 shows an example of legislation that a vehicle must meet before it has been released to the European market. Only by satisfaction of these regulations a license for sharing the market is obtained. Part of these regulations applies to the ecological characteristics of a vehicle.

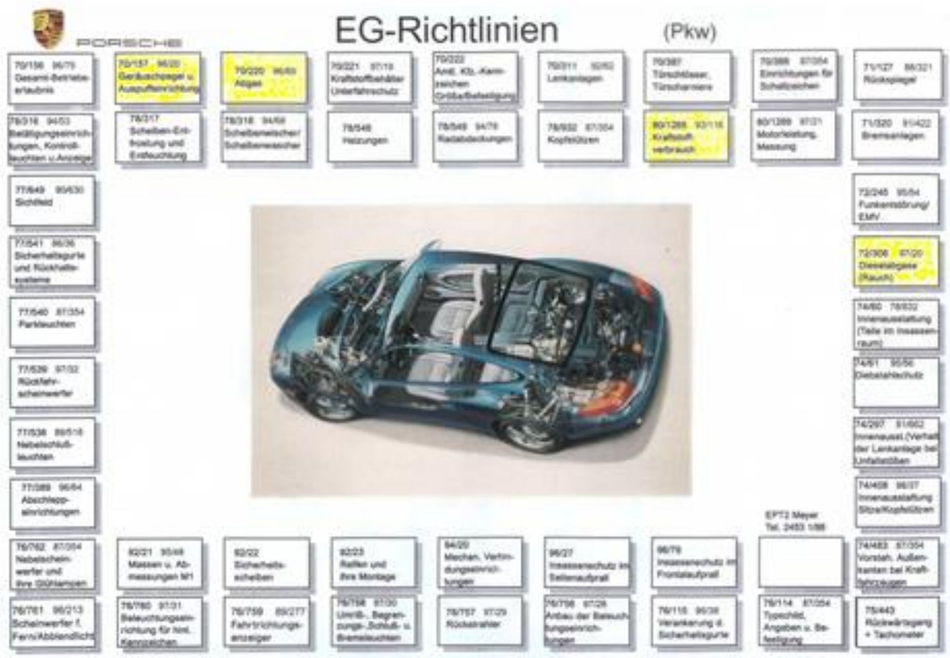


Figure 3 Regulations concerning vehicle registration

Similar, but not the same requirements exist in the United States, Japan, Australia and other countries.

EXHAUST EMISSION

The first legislation on the limitation of exhaust emissions from passenger vehicles were passed in California, in 1966. They have a pioneering role in the development of the vehicles in all the countries of the world. Nearly over the past 50 years, they have evolved considerably in their shape, complexity and application areas.

The first directive on limitation of exhaust emissions of passenger vehicles in Europe was adopted in 1970 (Directive 70/220/EC). Since then, it has been changed ten times and is obligatory for all EU member states.

Directive 98/69/EC defines limit values for the following components of the exhaust emissions of Otto and Diesel engines:

- Carbon Monoxide (CO)
- Unburned hydrocarbons (HC)
- Nitrogen oxides (NOx)
- Solid particles and soot, particulate mas (PM) and particulate numbers (PN)

With the application of Directive 75/2007/EC, a request for further reduction in emissions is set in the EU through so-called Euro 5 and Euro 6 limit values (Table 2 and Table 3).

Table2 EU - Exhaust Emission Limits for passenger vehicles with gasoline engines

Introduction year		CO [g/km]	THC [g/km]	NMHC [g/km]	NOx [g/km]	PM [g/km]	PN [N/km]
2000	Euro 3	2,3	0,2	-	0,15	-	-
2005	Euro 4	1,0	0,1	-	0,08	-	-
2009	Euro 5	1,0	0,1	0,068	0,06	0,0045	-
2014	Euro 6	1,0	0,1	0,068	0,06	0,0045	6x1012

Table3 EU - Exhaust Emission Limits for passenger vehicles with diesel engines

Introduction year		CO [g/km]	HC+NOx [g/km]	NOx [g/km]	PM [g/km]	PN [N/km]
2000	Euro 3	0,64	0,56	0,50	0,05	-
2005	Euro 4	0,50	0,30	0,25	0,025	-
2009	Euro 5	0,50	0,23	0,18	0,0045	6x1011
2014	Euro 6	0,50	0,17	0,08	0,0045	6x1011

Starting with Euro 4 regulation, all parts of the vehicle that affect exhaust emissions must prove their useful lifetime for 100.000 km, and starting from Euro 5 regulations, their lifetime was extended to 160.000 km.

Situation in the field of legislation in the United States has become difficult to overview due to the parallel legislations in California and 49 other states, but also due to many special rules and extensive lists of possible combinations.

In September 1990, the California Air Resource Board (CARB) has adopted a program called "Low Emissions Vehicle Regulations" (LEV). This program demanded continual introduction of a growing number of “clean vehicles” to market by the automotive industry, with continuous exhaust emissions control (On Board Diagnose, OBD). For the first time, four categories of vehicles were introduced which had to continuously meet the increasingly stringent legislation:

- TLEV - Transient Low Emissions Vehicles (since 1995)
- LEV - Low Emissions Vehicles (since 1988)
- ULEV - Ultra Low Emissions Vehicles (1998)
- ZEV - Zero Emissions Vehicles (2% by 1998, 10% since 2010)

Since the demand for ZEV could not be reached until today, the law had adopted LEV II regulation in 1998, which introduced two categories of vehicles:

- SULEV - Super Ultra Low Emissions Vehicles and
- PZEV - Partial Zero Emissions Vehicles.

New LEV III regulation was adopted in 2012, which tightens the limits for HC, NOx and PM, and applies to all vehicles from 2020.

In almost all modern countries of the world, regulations on limitation of exhaust emissions are in force and are based on the legislations of the European Union, the United States or the laws of Japan (Fig. 4).

There is a common principle that the tests are carried out on the test bench and that they have their own, specifically prescribed pattern of driving. Differences in testing methods in the EU, USA, Japan, are increasing significantly the cost of development and homologation for producers who offer their vehicles to the global market.

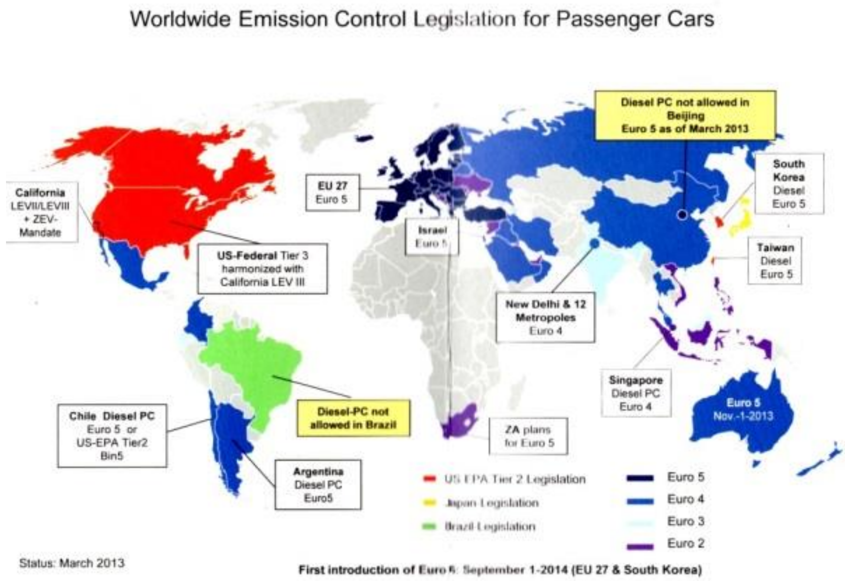
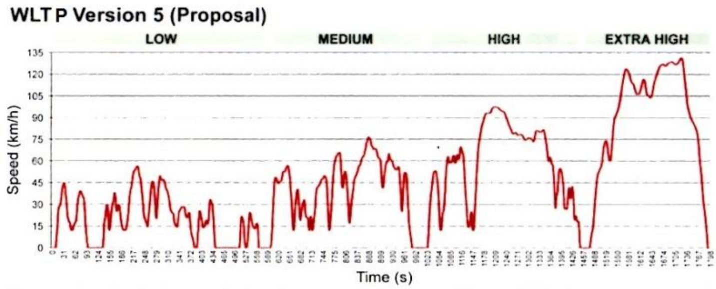


Figure 4 Exhaust Emission Regulations worldwide

Desire to create the world's uniform, joint regulations penetrates very slowly the awareness of legislators. The first goal is to consent to a harmonized, valid for the whole world test for determination of vehicle exhaust emission and determination of vehicle's safety. For years, there is a proposal for a unique cycle for determination of emissions, so called World Light Duty Test Procedure (WLTP) (Fig. 5).



	NEDC [1]	WLTC
Length (s)	1.220	1.800
Length (km)	11,06	23,26
Idle time (%)	33	13
V_{max} (km/h)	120	131,6
$V_{average}$ (km/h)	31,6	46,3
$Accel_{max}$ (m/sec^2)	1	1,6

[1] NEDC = New European Driving Cycle - ECE + EUDC

Figure 5 World Light Duty Test Procedure (WLTP, proposal)

FUEL CONSUMPTION AND CO2 EMISSION

Fuel consumption is measured in parallel with the measurement of emissions.

In the EU, fuel consumption is not directly limited, but, since 1978, the manufacturers are required to provide information on the amount of fuel consumption. The fuel consumption is indirectly limited through CO2 emissions. Between CO2 emissions and fossil fuel consumption (B) there is the following dependency:

- CO2 = 24 x B [l / 100 km] for vehicles with spark-ignition engine,
- CO2 = 27 x B [l / 100 km] for vehicles with diesel engines.

With regulation 443/2009 EC, the average CO2 emission of a manufacturer's fleet must be reduced to 120 gCO2 /km (about 5 l / 100 km) from 2012 to 2015. Until 2021, this value must be reduced to an average of 95 gCO2 / km (approximately 3,5 - 4,0 l / 100km) (Fig. 6).

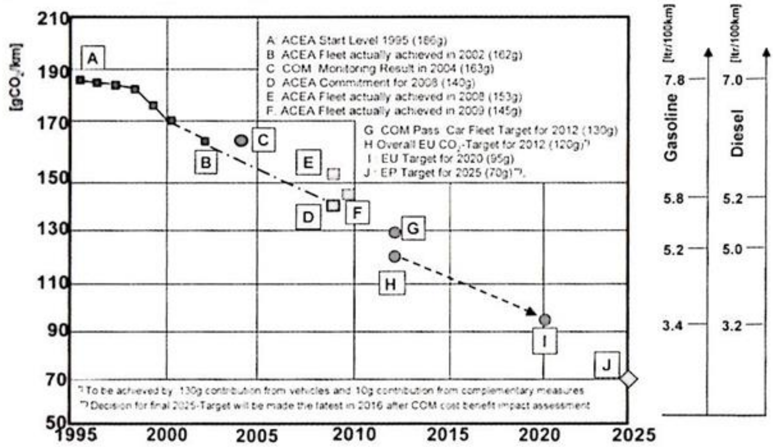


Figure 6 Reduction of CO2 - Emissions and fuel consumption in the EU

In the United States, the fuel consumption was limited to 27.5 mpg (8.55 l / 100 km) by so called CAFE standard (Corporate Average Fuel Economy) since 1978. In 2010, the United States adopted new rules for fuel consumption and CO2 emissions. Limit values for fuel consumption and CO2 emissions depend on the so-called "Footprint" or geometrical area of the vehicle (Fig. 7).

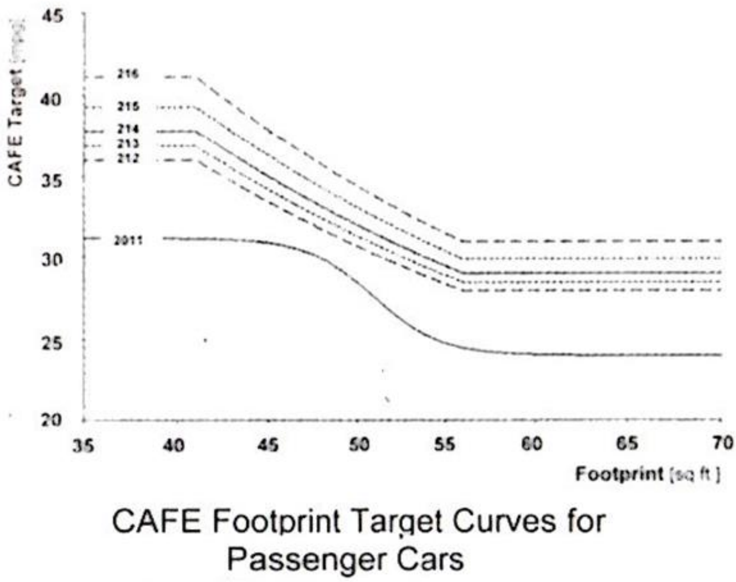


Figure 7 CAFE footprint target for fuel consumption

VEHICLE NOISE

In the EU, regulation 70/157 / EC on the limitation of noise of passenger vehicles applies since 1966. At regular intervals, permitted noise of the vehicle has been reduced from 84 dB(A) to currently valid 74 dB(A). In addition to the first source of noise, the engine and transmission, other relevant sources have been observed: aerodynamics, tires, road condition, etc. One of the proposals in the EU is to reduce tire noise to

- 72 to 76 dB(A) for passenger vehicles and
- 76 to 79 dB(A) for commercial vehicles.

Vehicle stationary emissions

In order to reduce the overall emissions of unburned hydrocarbons emitted by a single vehicle, HC-emissions of a parked vehicle, resulting from evaporation of fuel, rubber, plastic and various adhesives, must also be taken into account.

Since 1983 in the United States and since 1993 in the EU, tests of vaporization of hydrocarbons of the entire parked vehicle have been effective, which are carried out in special chambers called SHED-test chambers (Sealed Housing for Evaporate Emission Determination) (Fig. 8).

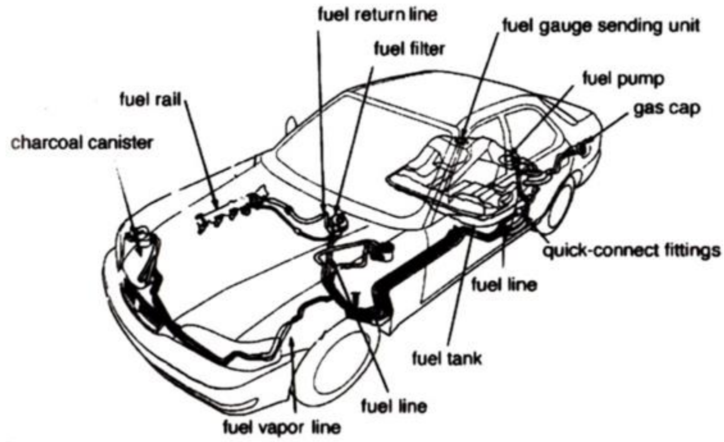


Figure 8 Source of the evaporative loses in a vehicle

ENVIRONMENTAL PROTECTION ACTIVITIES IN AUTOMOTIVE PRODUCTION

Automotive production is associated with the consumption of raw materials, energy, water and air. In addition to the desired product - vehicle, there are side effects like the resulting exhaust gases, excess heat, waste water and other waste.

Impact on the environment (air, soil, water) during production has not yet been possible to avoid, but, today, the development of a product without considering its environmental impact on the entire journey from "cradle to grave" is no longer possible. Since the beginning of the 1980s, regulations on environmental protection during production have continually been tightened.

ENERGY CONSUMPTION

According to data of different manufacturers and depending on the size of the motor vehicle, vehicle production consumes about:

1.6 to 7.2 MWh per vehicle

out of which, approximately:

0.4 to 3.2 MWh of electricity and

1.0 to 4.5 MWh of thermal energy.

During vehicle lifetime, about 10 to 15% of the total consumed energy is spent on vehicle production. In this, the largest consumer of energy is vehicle paint coating process. As energy costs account for about 30% of the vehicle production costs, the energy saving is one of the main aims not only in protection of the environment, but it also affects the reduction of production costs.

EXHAUST EMISSION

Modern vehicle production is still accompanied by the exhaust emission. The following emissions are formed during vehicle production:

- Carbon monoxide (CO), 0.2 - 1.7 kg/vehicle
- Nitrogen oxides (NOx), 0.3 - 0.8 kg/vehicle
- Sulphur dioxide (SO2), 0.0 - 0.8 kg/vehicle
- Solid particles, soot (PM), 0.05 - 0.3 kg/vehicle
- Organic substances (VOC), 1.0 - 7.9 kg/vehicle
- Carbon dioxide (CO2), 1.0 -1.7 t/vehicle

Since 2005, the industrial plants with power greater than 20 MW must seek permission for the maximum permitted amount of CO2 emission.

Since September 1987, 87 world countries have signed the so-called "Montreal Protocol", which prohibits the use of fluorine-chlorine-hydrocarbons (FCHC), which are considered to endanger the ozone layer in the stratosphere. In air conditioning systems, FCHC were first replaced with R134a agent, which is not harmful to the ozone layer. But, as R134a has a greenhouse effect (Global Warming Potential, GWP of 1430), its use is prohibited by directive 2006/40/EC from January 1st, 2011. Instead of it, agents R-1234yf (GWP=4.0) and R744 (CO2, GWP=1.0) are being tested.

Large environmental loads were noted during application of solvents based on hydrocarbons in the process of vehicle painting. Application of paints based on water solvents or based on powder (without solvent) and investments in new paint shops, have contributed to significant reduction in HC emissions in vehicle production (Fig. 9).

Figure 9 Reduction of the VOC emission of German automotive manufacturer

WATER CONSUMPTION

Relatively large amounts of water are used during vehicle production:

- 2.3 to 8.0 m3/vehicle in the production of passenger vehicles.

Therefore, the rational use of water is one of the important aspects of environmental protection.

In modern vehicle production, water is recycled and repeatedly applied. Every litre is used up to 120 times again, before it has been purified and released to sewage.

WASTE

Passenger vehicle production is accompanied by approximately 60 different types of waste. All waste must be included in the so-called "roundabout" (recirculation) of waste. Therefore, it is necessary to selectively collect waste directly at the source.

The amount of waste generated in the passenger vehicle production share is:

- 35-150 kg/vehicle of industrial waste and waste similar to household waste and
- 0.5 to 15 kg/vehicle of water treatment waste (sediment, sludge).

European Waste framework directive (2008/98/EC) defines only two types of waste:

- waste for recovery and
- waste for disposal.

Main objective of ecological waste treatment is to reduce its quantity. True engineering solution is so-called "Technical waste reduction", which is achieved by the inclusion of ecological thinking in the planning, design and development of products (so-called "Design for environment"). The ideal goal of ecological production is “Zero emission and waste production”.

ENVIRONMENTAL AUDIT

Control the organizational and technical measures in the field of environmental protection in the vehicle production is done through so-called environmental auditing. European Union directives 1836/93/EC and 1221/2009/EC speak of "voluntary participation of organizations in the common system for environmental management and environmental protection control". These directives are known as EMAS - "Eco Management and Auditing Scheme". In the foreground, there are "prevention, reduction and, if possible, avoidance of impacts on the environment, possibly already at the source, as well as the rational use of resources of raw materials and the use of clean technologies."

EMAS represents a comprehensive survey of the environmental situation of enterprises and assessment of the ecological status and its impact on the environment (Fig. 10).

The main element of the regulation on environmental auditing is to create a system of environmental management. This system should help the company to improve its efforts in the field of nature protection during the entire life of the vehicle.

Prerequisite for creation of ecological management is the integration of the idea of protecting the environment into general goals and policies of the company. This system must include all parts of the company: research, development, procurement, production, sales, personnel department, finance department, quality control, work safety, etc. System for environmental protection must provide the fulfilment of all legal requirements and its own set of environmental goals.

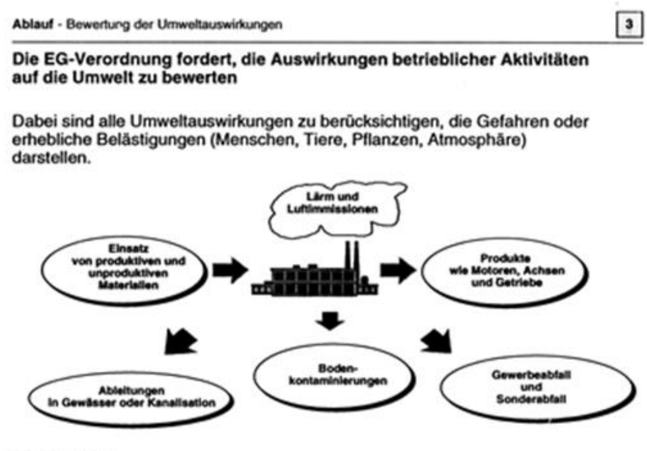


Figure 10 EMAS: Impact of corporate activities on the environment

In accordance with EMAS, companies are required to document their organization and activities in the field of environmental protection, at all levels. The regulation prescribes the exact method of auditing. The final process of eco-auditing is the publishing of "Environmental Report", which is checked by a neutral experts, whether the whole procedure corresponds to the European regulations. Based on the positively estimated "Environmental report", the company is entered into the eco-register and gets

"Environmental certificate." The once obtained certificate is not valid forever, but must be renewed every third year.

Table 4 EMAS and ISO 14000

Criteria	EC – eco audit	ISO – Norm 14001
Application	All organization wishing to an environ-mental-oriented leadership	For companies of any kind and parts thereof, not location related
First environmental assessment	required	Recommended
Review of the environmental management System	Comprehensive environmental review required every 3 years	Regular auditing prescribed , bat without Absolute time schedule
What is covered?	All environmental-related activities, products and services	Environmental aspects that appear to be controlled
Continuous improvement	The corporate environmental protection in terms of reducing environmental impact	Of impacts on the environment
Technical measures	Application of “best available, commercially reasonable technology” to reduce the environmental impacts	Taking into account “technical options”
Environmental Report	Must be created and declared valid	Not required
Verification/acceptance	Assessment with participation statement	Certification/Certificate
Make public	Obligation to publish the environmental report	Obligation to publish the environmental policy
Worldwide	Across the EU, regulated by law, includes rules for authorization procedure for environmental experts	Worldwide

Regulation EMAS is not the only possible control of environmental measures. All organizations have a choice between the European EMAS regulations and international standard ISO 14001. Table 4 shows the similarities and the differences between these two systems of environmental auditing.

Organization of management of environmental protection system is similar to the organization of management of quality control.

TECHNICAL MEASURES FOR REDUCTION OF EMISSIONS FROM OTTO AND DIESEL ENGINES

Despite the intensive efforts and numerous attempts to find another power drive for motor vehicles, IC engine has remained the undisputed power drive, not only for vehicles, but also for many other application areas. For almost 140 years, Otto and Diesel engines show that they are the best response of engineers to offer of so far the most comfortable and the cheapest energy source - oil. No other power unit has so far succeeded to use the energy contained in fossil fuels with such high efficiency.

Both engine versions will retain its importance as power units of motor vehicles for the foreseeable future. This means that the development in terms of reducing the fuel consumption and exhaust emissions will be intensively continued.

In addition to the theoretically comparative Otto and Diesel engines cycles, which take into account only the engine's economy, a new theoretical cycle was patented in 1975, which takes into account the reduction of exhaust emissions (HC and NOx) - the so-called thermodynamic cycle with isothermal expansion, as shown in Figure 11.

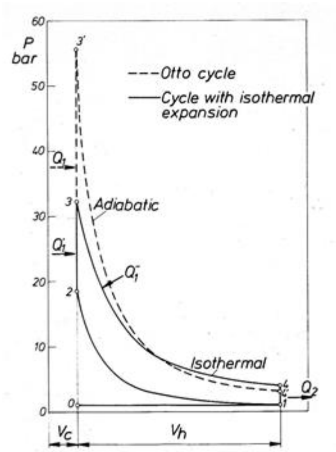


Figure 11 Otto cycle and thermodynamic cycle with isothermal expansion

It has been established that modern Otto and Diesel engines with multiple direct injection work according to this cycle.

Since the first introduction of legislation on the restriction of exhaust emissions in the early 1970s, for the existence of engines it is crucial for them to meet all the existing and planned regulations on the reduction of negative environmental impact. Otto and diesel engines have shown incredibly great potential for development, which had provided their inviolability up until today. Measures for minimum exhaust emissions and reduction of fuel consumption (and, hence, CO2 emissions), include optimization of a large number of parameters and systems. The most important of them are summarized in Tables 5 and 6.

Table 5 Measures to reduce „Raw" emission in the cylinder

Measures to reduce "Raw" emission in the cylinder

Gasoline engine

A. Operating parameters
- mixture formation system
- control of mixtures into each cylinder
- optimization of the ignition timing
- precise exhaust gas recirculation

B. Design parameters
- compression ratio
- piston diameter and stroke
- variable intake system
- variable valve timing
- minimization of dead spaces in the combustion chamber
- Reduction mechanical losses

Diesel engine

A. Operating parameters
- air mixture, swirl
- injection pressure (> 2.000 bar)
- moment and law of injection
- precise exhaust gas recirculation
- charging with cooling of intake air

B. Design parameters
- 4 valves per cylinder
- combustion chamber shape
- compression ratio
- location of the injector
- minimization of dead spaces in the combustion chamber
- Reduction mechanical losses

Table 6 Reduction of emission in the exhaust system

Reduction of emission in the exhaust system

Gasoline engine
- installation of 3-way catalyst near the engine
- reduction of heat capacity of exhaust system
- two λ – probes per catalyst
- thermally well insulated exhaust system
- controlled introduction of secondary air
- possible electric preheating of the catalyst

Diesel engine
- oxidation catalyst
- reduction catalyst
- selective catalyst
- NOx – absorption catalyst
- Particulate filter
- particulate filter with continuous regeneration

In addition, all vehicles must have a tank with active carbon to reduce evaporation from the stationary vehicle, as well as a complete system for controlling exhaust emissions during exploitation (OBD).

Discussion on the impact of CO2 emissions on possible climate changes has particularly intensified the efforts to reduce the fuel consumption, which follow the development of the engine from the very beginning. Development of new materials, the use of new production technologies and control and management of engine processes, constantly open new ways to reduce fuel consumption.

Vehicle noise

Among all the negative impacts on the environment, vehicle noise represents the most sensitive problem. The engine exhaust system has a special role in this, where specific task is the integration of the catalytic converter and muffler. Complex exhaust systems of modern vehicles require careful development, as well as all other systems for noise reduction and isolation (Fig. 12).

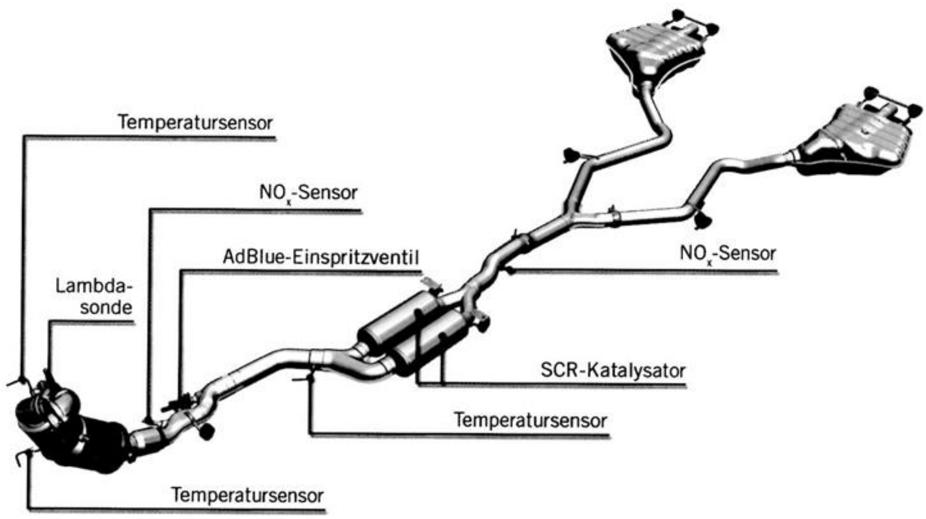


Figure 12 Modern engine exhaust system

IMPORTANCE OF FUELS

Solution to the problem of "Impact of vehicles on the environment" cannot be found only at the development departments of the automotive industry. A significant part of the solution is found at producers of energy or fuels for vehicle engines. Because "clean" engines require "clean" fuels. Therefore, the cooperation between the oil and automotive industries is of particular importance.

Opportunities provided by new engine concepts and new technologies for exhaust gases after treatment, can be fully used only if the whole system is optimized. Fuel, as an important part of the engine, must be included in the system optimization.

Major global automotive producers have set requirements that fuels must meet in order to be successfully applied in modern engines at the so-called "World Wide Fuel Charter". After the elimination of lead, reduction of the amount of aromatics, especially benzene, attention was paid to the reduction or complete removal of sulphur from the fuels, because the least amounts of sulphur have negative effect on the operation of the system for the exhaust gases treatment.

VEHICLE IN TRAFFIC

When a new vehicle has successfully passed all the homologation tests and is put into traffic, the public begins to detect all positive and all negative vehicle features.

Directive on consumer information requires that consumers must be informed on fuel consumption and CO2 emissions when vehicle is sold, because they can influence the decision to purchase the vehicle (Fig. 13).

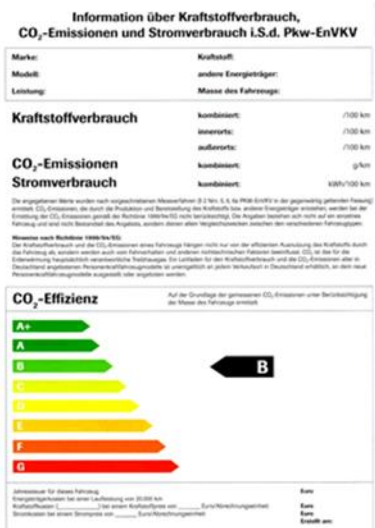
Vehicle exhaust emissions and noise are controlled during the specified vehicle lifetime. Producers have to guarantee that their vehicles meet the exhaust gas regulations during the lifetime of 160.000 km (EU Regulation from 2010).

In the first place, there is the reduction of evaporative emissions of fuel in transport, during pump station supply and during refuelling of the vehicle tank (Fig. 14).

Control of vehicle exhaust emission in traffic is done by so-called On Board Diagnostics (OBD), which was first introduced in the USA in 1994 and in Europe since

January 1st, 2000. OBD provides continuous electronic control of all vehicle parts relevant for exhaust emissions.

If any of the systems is not operating, the so-called MIL (MIL - Malfunction Indicator Lamp) lights up on the dashboard of the vehicle. Despite the presence of the OBD, in many countries, it is biannually checked by special examination (AU - Abgasuntersuchung) weather the engine is tuned according to the producer's regulations.


Information über Kraftstoffverbrauch, CO_2-Emissionen und Stromverbrauch i.S.d. Pkw-EnVKV

Marke: Kraftstoff:
Modell: andere Energieträger:
Leistung: Masse des Fahrzeugs:

Kraftstoffverbrauch kombiniert: /100 km
innerorts: /100 km
außerorts: /100 km
CO_2-Emissionen kombiniert: g/km
Stromverbrauch kombiniert: kWh/100 km

CO_2-Effizienz

A+
A
B
C
D
E
F
G

B

Figure 13 Information on fuel consumption and CO2 emission

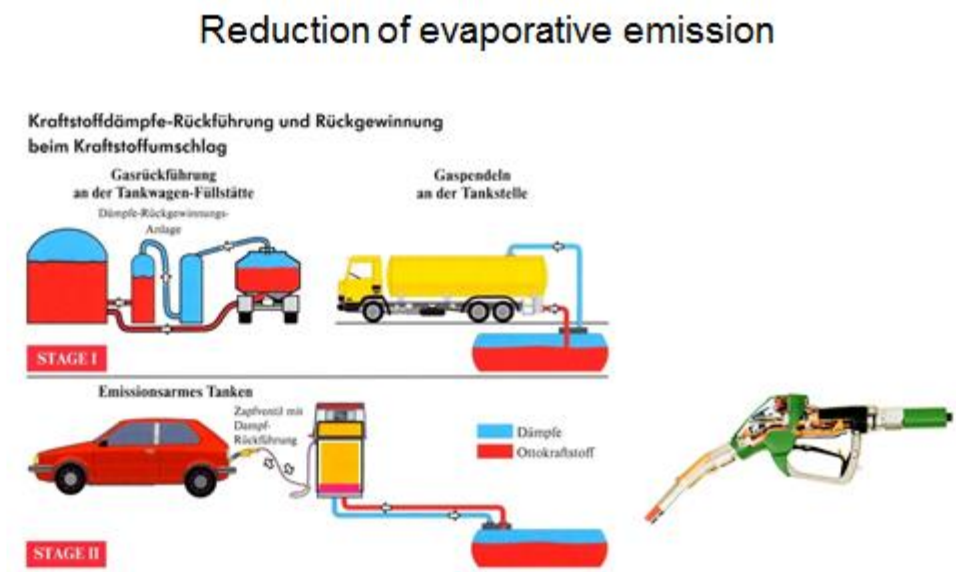


Figure 14 Reduction of evaporative emission during refuelling

Vehicle noise control in traffic is carried on the parked vehicle with the engine running at idle speed, according to ISO 5130 standard.

The traffic, especially the vehicle traffic, is the base for supply and existence of the economy and modern society and a prerequisite for a high standard of people, jobs and social security.

In parallel with the development of transport, the growing desire of individuals and society for a life oriented toward environmental requirements has been observed in the last decade and without changing the existing structures of the economy, demand and desire for mobility. Everyone wants to be mobile, but does not want to suffer the burdens arising from traffic. So, one of the primary tasks of the automotive industry is to improve the efficiency of transport systems, while minimizing burdens on the environment caused by it.

Energy consumption is one of the first criteria for assessing the ecological characteristics of individual transportation system. In the first place, for its reduction, there is ensuring its smooth traffic flow. Traffic flow often forces the driving style, in which the fuel consumption, the exhaust emissions and noise are very unfavourable (Fig. 15).

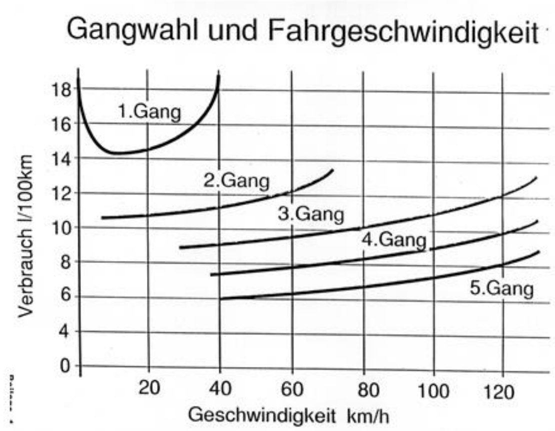


Figure 15 Influence of gear selection on fuel consumption

The lower the average speed in urban traffic is, the greater the fuel consumption and exhaust emissions are.

Prerequisite for traffic to fulfil its function is the existence of appropriate infrastructure. Traffic flow depends not only on the number of vehicles, but also on the state of the roads and on traffic organization. To organize the traffic by intelligent planning means its simultaneous environmental planning. It is often possible, for example in freight traffic, to realize the same transport capacity with much lower fuel consumption, that is with lower costs and less environmental loads (Fig. 16).

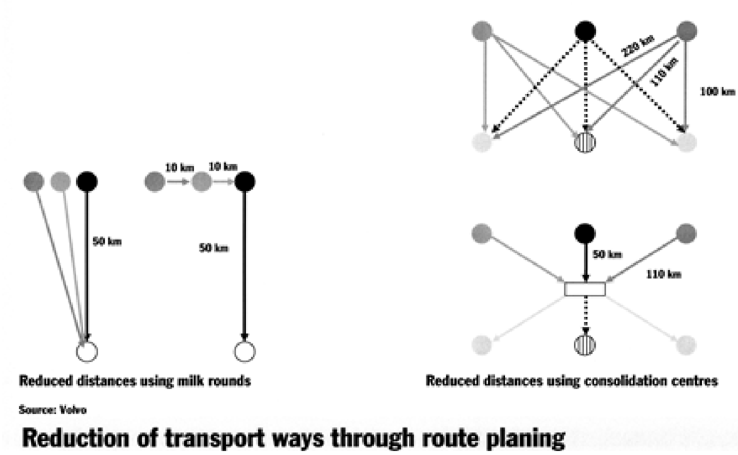


Figure 16 Reduction of transport ways through route planning

In many places, it is no longer possible to build additional traffic infrastructure. Great expectations in terms of solutions of acute traffic problems and the associated environmental loads lie in the systems of modern information and communication technology (telematics). Although this technology is still in its infancy, the following results were registered:

- reduction of the number of traffic accidents for 20 to 30%,
- 10% reduction in fuel consumption and CO2 emissions due to reduced traffic jams,
- 5% reduction in fuel consumption and CO2 emissions due to reduction of driving time in the search of target and
- 5% reduction in fuel consumption and CO2 emissions through better links between individual and public transport.

Besides all the technical improvements on the vehicle and its power unit, in the choice of vehicle size, in capacity utilization and the like, the individual driving style of each driver greatly affects the fuel consumption, exhaust emissions and vehicle noise. Modern, highly developed vehicles can develop their own features, only by their proper use. Misuse of technology can completely cancel many good vehicle qualities.

At a certain constant speed, the fuel consumption can be doubled if the gear is not well chosen. The differences in fuel consumption up to 36% are often measured on the same vehicle, in the same traffic conditions, which were caused by a variety of drivers with different driving styles (Fig. 17).

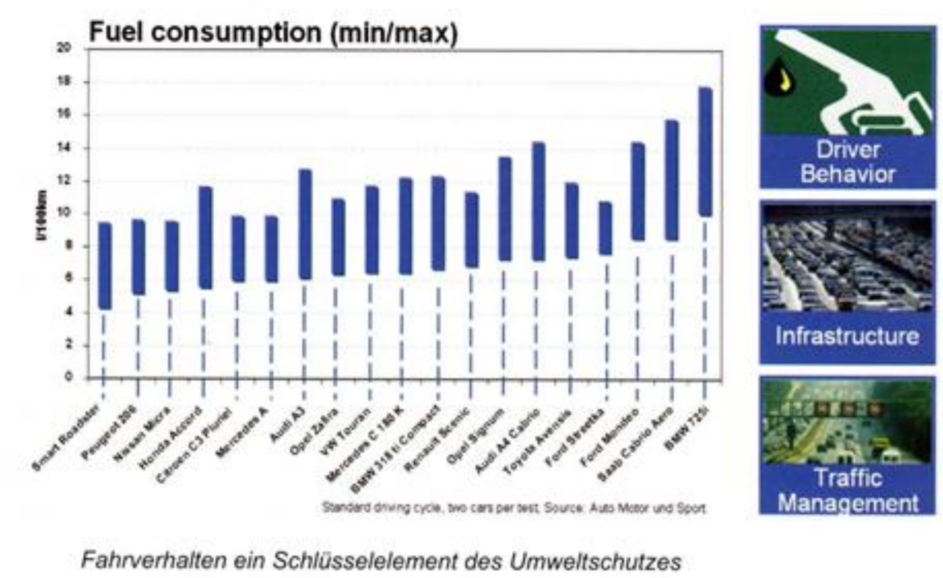


Figure 17 Driver's behaviour is a key element of environmental protection

RECYCLING

The average lifetime of passenger vehicles in the EU is around 10 to 14 years. After that, the question is what to do with the old vehicle? It consists of about 10.000 different parts and 40 different materials. The largest portion of these materials are iron and steel, light metals (Al and Mg) and plastics.

After the World War II, technologies for obtaining materials from old vehicles were developed in the world, so that the percentage of recycling amounted to about 75% of vehicle weight for a long time.

The efforts of modern society to reduce the negative impact of human activity on nature did not leave the end of product functions outside attention. In October 2000 End of life vehicle (ELV) regulation was adopted which applies to all EU member states. In accordance with this regulation, vehicle makers were required to, first provide stations for free admission of worn out end of life vehicles

Since January 1st, 2006, all new vehicles put into traffic must prove that their recycling quota amounts to 85% of vehicle weight, out of which, only 5% may be thermally utilized and 15% of vehicle weight may be disposed on landfills. Since January 1st, 2015, new vehicles must meet a quota of 95% recycling, with up to 10% of energy use.

For all vehicles produced after July 1st, 2003, law prohibits, with some exceptions, the application of lead (Pb), cadmium (Cd), mercury (Hg) and hexavalent chromium (Cr VI).

For each vehicle, there has to be a manual for dismantling the vehicle with information on the treatment of the parts and components of the vehicle. Therefore, already at the stage of defining the structure of a new vehicle, requirements on recycling are also set. "Design for recycling" is a new branch of activities of designers in the automotive industry. As over 70% of vehicle parts are produced by the supporting industries, the cooperation between vehicle manufacturers and their suppliers is very important. For that purpose, the so-called International Material Data System (IMDS) has been developed in order to accurately describe the chemical composition of all parts of the vehicle, so the 95% quota can be met.

LIFE CYCLE ASSESSMENT

Production system of the vehicle includes its development, production, exploitation and recycling of end of life vehicles. A comprehensive instrument for assessing the environmental impact of the product throughout the whole lifetime is the ecological balance or Life Cycle Assessment (LCA). In accordance with the ISO 14000 series, LCA is defined as "the systematics in the collection and analysis of data at the input and output of materials and energy into a certain system and of their impact on the environment, which are related to the function of the product throughout the life cycle" (Fig. 17).

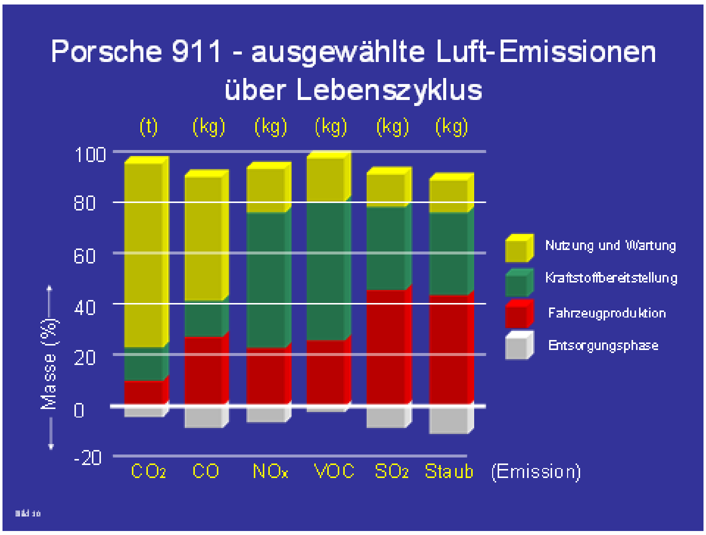


Figure 18 Life Cycle Assessment of Porsche 911

The LCA should point to ways for further improvement of the environmental characteristics of vehicles during the whole of his "lifetime”. It is a new, relatively young scientific discipline, which is still in development.

PROSPECTS FOR THE FUTURE

All parameters now indicate that the vehicle will retain its primacy as a means of transport for the foreseeable future. Its replacement has not been found yet. Of course, all the demands placed before it by the increasing density of traffic, especially in large crowded cities, will still have to be met, with all the problems related to energy consumption and environmental pollution.

Question of vehicle’s power unit will find its answer primarily in energy offer at the market. Predictions about the quantity of existing oil reserves do not change for decades. Even today, as well as half a century ago, it is said that they will last for another 30 to 40 years. But, regardless of the availability of the reserves, it is known that they are limited and, therefore, the search for other fuels is the constant companion of development in the automotive industry.

The intensive search for alternative vehicle power units for more than 100 years had showed that none of the proposed systems, in the sum of their properties, could compete with a four-stroke IC engine. At the beginning of the 21st century, it is considered that the IC engine will be the main power unit for vehicles in the next 20 to 30 years. The only alternative that does not replace but complements the IC engine is the so-called hybrid drive, a combination of engine drive and additional electric drive. Vehicle with pure electric drive or drive based on so-called fuel cells will not be applied in mass transport for a long time.

But, regardless of which power unit would drive the vehicles, the requirements of environmental protection will become increasingly stringent. The future power units, new materials and new fuels will also have to fulfil all environmental regulations at all stages of vehicle life cycle, from obtaining the raw materials to recycling the products. Because one thing would not change - the four elements on which the ancient world rested: air, water, earth and fire, will still remain of paramount importance for the survival of mankind.

REFERENCES

[1] Gruden, D.: Umweltschutz in der Automobilindustrie. Vieweg+Teubner Verlag, Wiesbaden, 2008

[2] Gruden, D.: Varovanje okolja v automobilni industriji. Založba Izolit. Kranj, 2011

[3] WHO – Guidelines for indoor air quality. WHO-Europe, Copenhagen, 2010

[4] MAK-und BAT-Werte Liste 2013.Deutsche Forschungsgemeinschaft. Mitteilungen 49/2013

[5] Worldwide Emission Standards and Related Regulations. Continental, March 2013

[6] Worldwide Emissions Standards. Passenger Cars and Light Duty Vehicles. Delphi, 2013/2014

[7] Umweltverträglichkeitsprüfung (UVP) – gute Aufwand-Nutzen-Bilanz. Umwelt, 5/2009

[8] EMAS – Novelle in Kraft getreten. Umwelt, 3/2010

[9] Internationales Wiener Motorensymposium. Wien, 2014

[10] 14^{th} International Symposium, Automotive and Engine Technology. Stuttgart, 2014

[11] Gruden, D: Thermodynamischer Prozess mit isothermer Expansion. Deutsches Patentamt P 2507 142.5. 19.02.1975

[12] Gruden, D.: Combustion and Exhaust Emisssion of an Engine Using the Porsche Stratified-Charge-Chamber-System. SAE-Paper 750888

[13] Warnecke,W.: Kraftstoffe für das 21. Jahrhundert. MTZ, Oktober 2006

[14] Gruden,I. et all: Neuer 14,8-L-NFZ-Motor von Daimler für den NAFTA-Markt. MTZ 74 (2013) 12

[15] Informations- and Kommunikationstechnologien für sichere und inteligente Fahrzeuge. Kommision der EG- Gemeinschaften, Brüssel, 2009

[16] Pflieger,I.: Grundsatz Ökobilanz. CTI – Forum CO2, Sindelfingen, 2007

[17] Directive 2000/53/EC of the European Parliament on End of Life Vehicles . 8. Sept. 2000.

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TECHNICAL INSPECTION OF VEHICLES AND ROAD SAFETY- INTERNATIONAL EXPERIENCE AND EXPERIENCE OF THE REPUBLIC OF SRPSKA

Snežana Petković [1]

UDC: 629.07

ABSTRACT: Technical inspection of vehicles has been identified worldwide as an essential element of road safety and accident prevention. The conclusion is, nonetheless, that very little is known about the effect of unroadworthy vehicles on road accidents. It is why many international studies have been conducted in order to determine the effect and also to introduce new methodologies for vehicle inspections that would reduce the number of road accidents.

This paper presents the results of international studies on the influence of vehicle technical inspection on road safety, and it also describes actions that have been implemented in the Republic of Srpska with the aim of improving road safety and roadworthiness.

KEYWORDS: technical inspection of vehicles, road accidents, road safety

TEHNIČKI PREGLED VOZILA I BEZBEDNOST PUTEVA – MEDJUNARODNO ISKUSTVO I ISKUSTVO REPUBLIKE SRPSKE

REZIME: tehnički pregledi vozila su identifikovani u svetu kao osnovni element bezbednosti puteva i prevencije saobraćajne nezgode. Zaključak je da se ipak vrlo malo zna o efektima neispravnih vozila na saobraćajne nezgode. Zato je realizovan značajan broj međunarodnih studija kako bi se utvrdio uticaj i uvele nove metodologije inspekcije vozila koja će smanjiti broj saobraćajnih nezgoda.

U ovom radu prikazani su rezultati međunarodnih studija o uticaju tehničkih pregleda vozila na bezbednost saobraćaja na putevima, a takođe opisuje akcije koje su sprovedene u Republici Srpskoj s ciljem poboljšanja sigurnosti na putevima i stanicama za tehnički pregled.

KLJUČNE REČI: tehnički pregled vozila, saobraćajna nezgoda, bezbednost saobraćaja

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TECHNICAL INSPECTION OF VEHICLES AND ROAD SAFETY-INTERNATIONAL EXPERIENCE AND EXPERIENCE OF THE REPUBLIC OF SRPSKA

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INTRODUCTION

Road safety is a problem of modern civilization. The problem has been present ever since motor vehicles appeared on roads. The increasing number of motor vehicles has lead to an increase in the number of injuries and fatalities in road accidents.

According to a report of the World Health Organization – WHO, published in 2004, 1.18 million people died in road accidents in the world in 2002 because of motor vehicles. This number included pedestrians and cyclists, as well as vehicle passengers, who were involved in the road accidents. Road traffic injuries are perceived as a price to be paid for mobility and are often neglected. Instead, they should be perceived as an illness that can be prevented to some extent, at least. In 2002, road accidents were the world's 11th most common cause of death, which equals to 2.1% of deaths worldwide and 22.8% of injuries resulting in death. Figure 1 shows the number of deaths caused by road accidents in the world (mortality rate per 100,000 population). It is obvious that Africa, Asia and parts of Eastern Europe have extremely high mortality rates caused by road accidents, [13].

As to Europe, according to data presented by WHO, statistical data show the scope of the road safety problem:

- 120,000 people die on European roads every year,
- 2.4 million people get injured,
- direct and indirect costs induced by traffic accidents in the EU-15 amount to 3% of the EU GDP (gross domestic product),
- there are 375 million road users, 200 million vehicles, and 1.3 million road accidents on EU-15 roads per year.

The preconditions for reducing the number of road accidents are as follows: improved vehicle safety, better road conditions, and maintenance of vehicle technical characteristics during exploitation.

Germany and other European Union member states had implemented many positive measures aimed at improving the level of road safety. To illustrate, in the period between 1970 and 2000, the number of vehicles tripled, whilst the number of fatalities caused by road accidents halved. Many reasons led toward this improvement: vehicles became safer; measures of active and passive safety achieved their goal; critical road sections were made less dangerous; new legislation also contributed to road safety improvement.

EU Action Plan envisaged a large number of measures pertaining to not only the behaviour of road users and improvement of roadworthiness but also to road infrastructure quality improvement. A European Parliament report stated the following: "If every road user fully complied with traffic regulations, the number of fatalities would reduce by 90%." In addition, if every driver wore their seatbelt, obeyed the speed limit, and were not driving

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under the influence of alcohol, the goal to halve the number of fatalities on European roads would be reached.

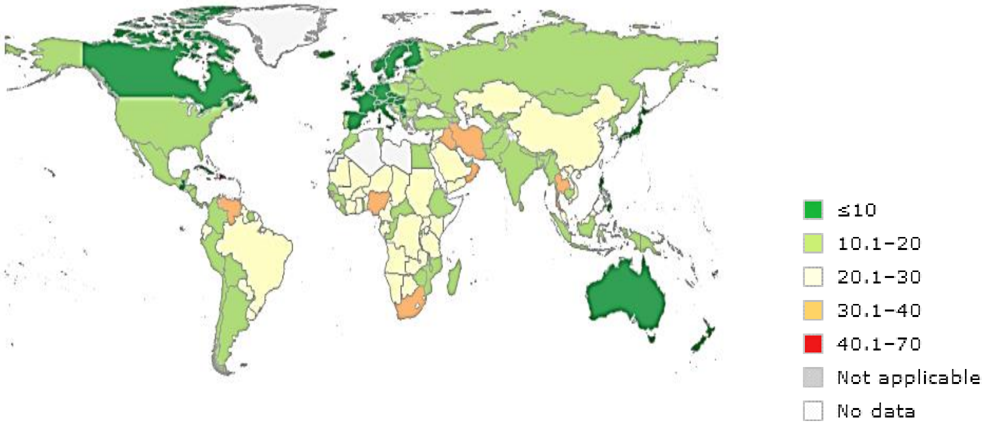

Figure 1 Number of deaths caused by road accidents in the world,2010, [13]

In the past few years, automobile manufacturers have also contributed to improving automobile safety by introducing the system of active and passive control. The installation of ESP system (electronic stability programme) in every motor vehicle, daytime use of headlights, and better pedestrian safety measures are only some of the measures that improve road safety. If there were options to reduce the average age of vehicles through tax breaks, and to increase the use of safety equipment in every automobile, these technical improvements would produce tangible results.

The quality and quantity of road networks is also an important factor of road safety, even though it might not seem obvious at first. Belgium serves as a positive example having introduced lighting on motorways, which provides optimum visibility at all times, including bad weather conditions. Measures of this kind, along with the improvement of road surface, better periodic maintenance, and intelligent management are only some of the positive examples of road safety improvement.

EFFECT OF UNROADWORTHY VEHICLES ON ROAD ACCIDENTS

It is normal for any vehicle that its features will deteriorate during exploitation. Unfortunately, many vehicle owners do not have their vehicles properly maintained and this results in a large number of unroadworthy vehicles being in use. The key question arises as to what extent unroadworthy vehicles affect road safety and the environment.

Many studies have been conducted in order to estimate the influence of unroadworthy vehicles on road accidents. The results of the studies vary a lot, ranging from some minor percentage to a significant 28%. Such a disparity is due to different work environment conditions (continents, weather conditions, inspectors, local economy, culture, political environment). Despite the differences, a conclusion can be drawn that unroadworthy vehicles have considerable influence on road accidents. It was concluded that the improvement of periodic technical inspections reduces the number of road accidents by approximately 5-10%. Additional improvement of other vehicle inspections, such as extraordinary inspections, significantly increases the above percentage, [12].

It has been noted that even with the introduction of new technical and technological solutions in the automobile industry aimed at improving road safety and ecological characteristics of vehicles, the number of road accidents in reality is still high and shows no signs of improvement. Therefore, the conclusion is that the need for the improvement of vehicle roadworthiness is now greater than ever.

Greater reliance on advanced technologies when driving has drastically increased the importance of roadworthiness. Any malfunction of these systems results in the loss of advantages that they can offer. Even though the control of mechanical systems within technical inspections is still a priority, a modern approach to roadworthiness must also include the control of new technologies and vehicle systems. Examples of new technologies that have been and are yet to be introduced are shown in Figure 2.

For example, the ESC and ACC systems (Electronic Stability Control and Active Cruise Control) reduce traffic risk by 20-40%. If this system is malfunctioning, it may represent a greater risk than vehicles with traditional braking systems. In fact, drivers will rely on new systems that will help them in critical situations and thus, they will change their driving behaviour. Also, the malfunction of some modern systems can lead to modern vehicles being less safe than traditional vehicles. For example, vehicles with airbags according to ECE94 and ECE95 have stiffer dashboards and interior than vehicles that are not equipped with airbags. It means that injuries will probably be more severe in the vehicles with airbags if the airbags are defective.

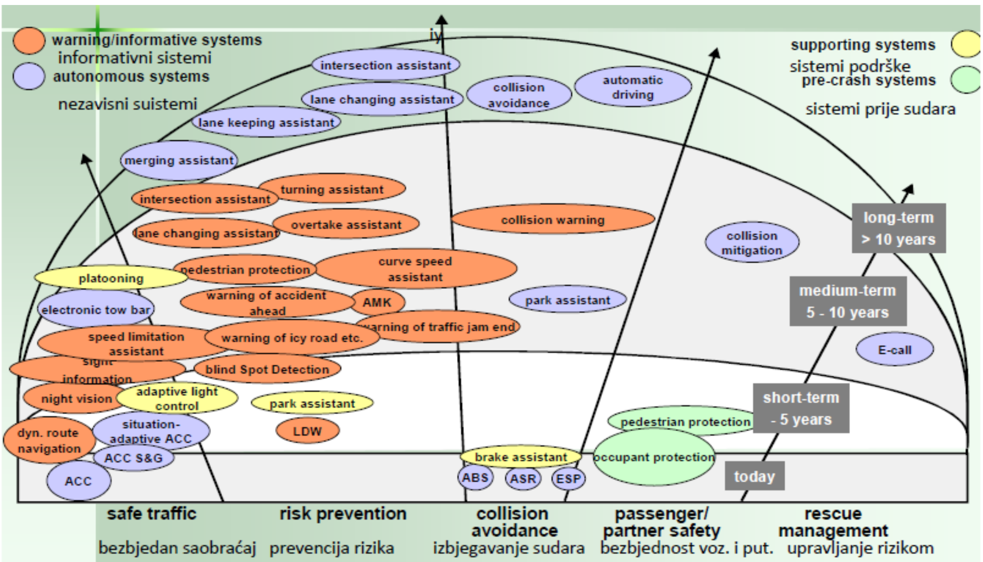

Figure 2 New vehicle technologies [12]

SITUATION IN EU REGARDING VEHICLE INSPECTION

There is no systematic research in EU member states on vehicle roadworthiness in the time period between periodic technical inspections. Data obtained from extraordinary vehicle inspections lead to a conclusion that there is a considerably large number of unroadworthy vehicles in use.

As to freight vehicles in particular, one should take into consideration the high rate of cancellations between periodic technical inspections. Figure 3 shows intervals for freight vehicle inspections, as recommended by the British Department for Transport in cooperation with freight vehicle operators' associations, and they are similar to those as recommended by vehicle manufacturers. Many freight vehicles reach between 50,000 and 200,000 km per year and thus need to be checked every 4 to 8 weeks, in addition to the mandatory annual technical inspection. Safety inspection intervals for all vehicles should fall between lines A and C or A and D as appropriate [3].

If the vehicle or trailer is 12 years or older then the SI interval should be no more than 6 weeks.The chart is only a guide and it is the responsibility of the operator, to increase the number of safety inspections should the operating conditions demand it. The actual inspection interval chosen should be determined by taking into account:

the age of vehicle/trailer;

the conditions under which a vehicle will be operated;

the expected annual mileage;

the recommendations of the vehicle manufacturer; and

other factors that may increase the risk of vehicles becoming unroadworthy.

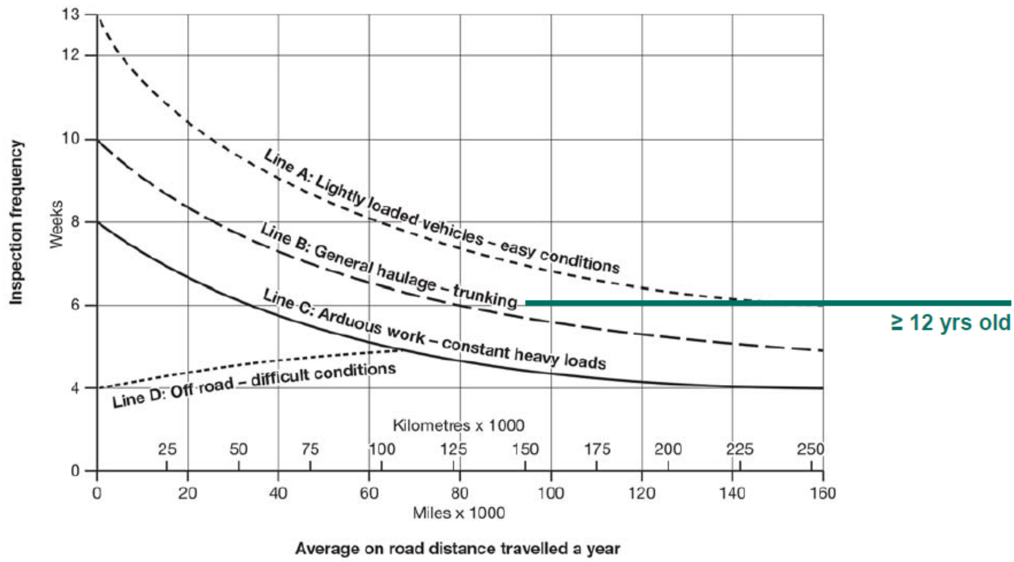

Figure 3 Recommended frequency of freight vehicle inspections in Great Britain [3]

Figure 4 shows the overall rate of unroadworthy vehicles in Germany over the period 1987-2005. It is obvious that the rate did not reduce considerably over the period.

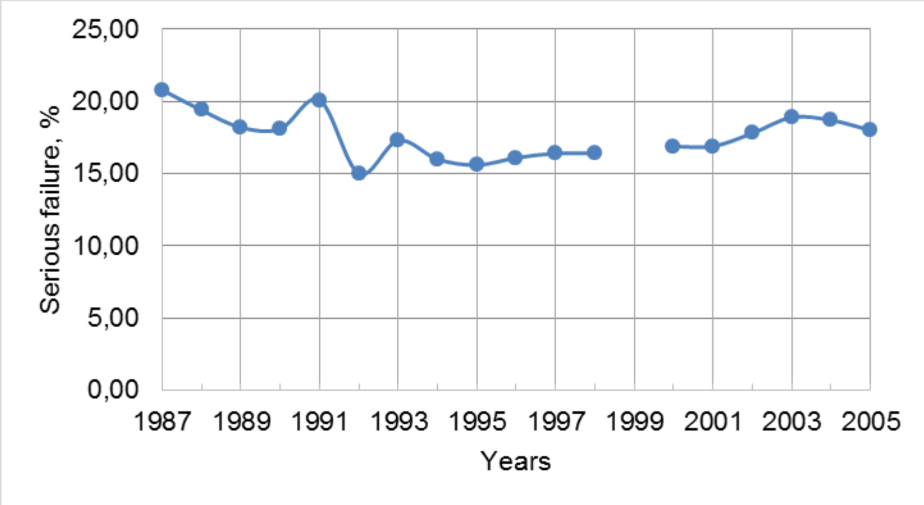

Figure 4 Average rate of unroadworthy vehicles in Germany between 1987 and 2005, [12]

Figure 5 shows the percentage of unroadworthy vehicles based on the total number of inspected vehicles in Great Britain, and it is over 50% for freight vehicles older than 10 years.

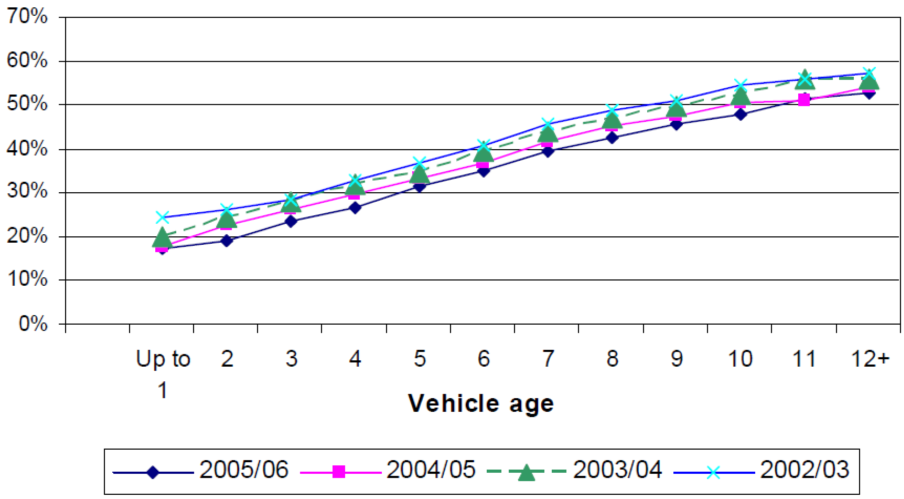

Figure 5 Percentage of unroadworthy freight vehicles out of total number of inspected freight vehicles in Great Britain, [12]

In 2004, 3.9% of freight vehicles and 4.1% of freight trailers were prohibited from movement due to heavy damage, whilst 7.4% of freight vehicles and 8.8% of freight trailers were prohibited from movement due to other faults. The most frequent problem was with faulty brakes and braking system, especially in case of older vehicles.

TECHNICAL MALFUNCTION AS A CAUSE OF ROAD ACCIDENTS

Technical malfunctions are certainly not the most common cause of road accidents. It is the human factor that has a much greater influence rather than technical malfunctions.

Nonetheless, road accidents caused by technical malfunctions can be avoided if the malfunctions are registered on time and removed within proper maintenance. Even so, over 26% of vehicles that participated in road accidents and were consequently examined by DEKRA experts in the period between 2001 and 2004, did have some technical malfunctions, sometimes very serious ones. These malfunctions were not always relevant for the accident, however almost one quarter of the examined automobiles that participated in accidents showed some malfunctions, either causal or non-causal, and therefore, they were malfunctions relevant for the accident, Figure 6.

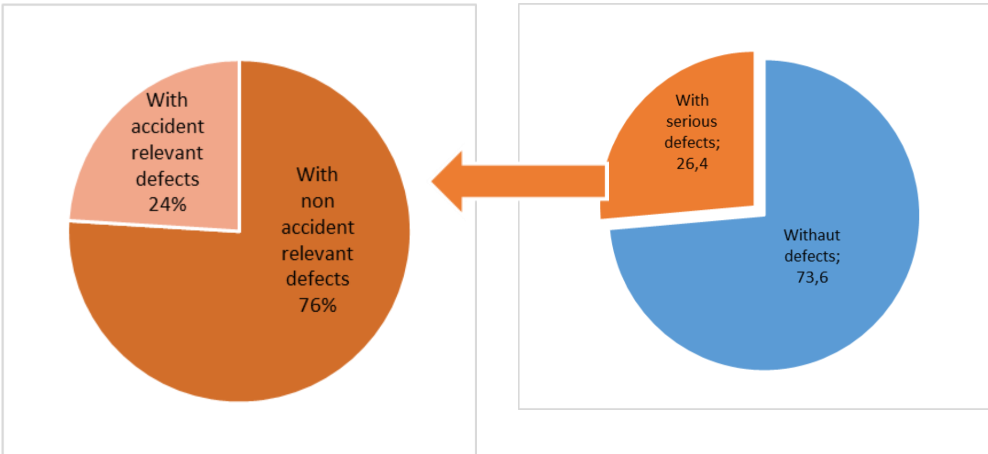

Figure 6 Defects in cars inspected after an accident (2001-2004), [6]

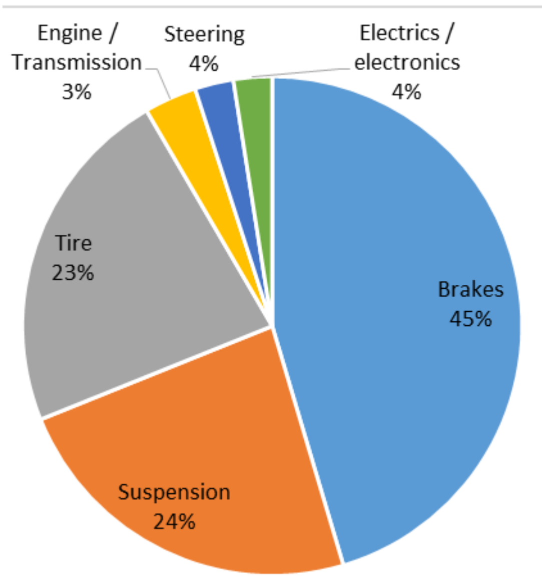

Figure 7 Malfunctions relevant for accidents grouped by assemblies, [6]

A more detailed analysis of malfunctions that cause road accidents showed that a malfunction in the braking system is the most common cause of accidents (45%), followed by a running gear malfunction – wheels, axles, suspension (23.5%) and defective pneumatics (22%), Figure 7.

It is therefore very likely that malfunctioning or inadequately repaired components of the braking system or old, worn-out and damaged pneumatics will cause accidents. The most obvious malfunctions can be detected by the driver or within automobile service checks or periodic technical inspections.

OVERVIEW OF PRESENT SITUATION AND WORK IMPROVEMENT IN TECHNICAL INSPECTION STATIONS IN REPUBLIC OF SRPSKA

The Law on the basics of traffic safety on roads in Bosnia and Herzegovina and the Regulation on technical inspection of vehicles regulate in a uniform manner the field of technical inspections of vehicles in Bosnia and Herzegovina, and in the Republic of Srpska [7, 11]. Licensing and supervision of technical inspection stations for motor vehicles and trailers is the responsibility of respective Ministries of Transport and Communications of the entities, cantons and Brcko District. The organizational scheme pertaining to vehicle technical inspections is shown in Figure 8, [9].

A very important position in the organizational scheme is held by the Expert Institution for vehicle technical inspection of the Ministry of Transport and Communications of the Republic of Srpska.

Along with various types of expert and technical support, the Expert Institution is in charge of the education and licensing of technical inspection stations staff.

In order to achieve the best possible quality of work, supervision over work, and a simplified vehicle registration procedure, all technical inspection stations have been linked to a single information system since 2009. This system links the vehicle inspection stations, the BiH Agency for identification documents, registers and data exchange (IDDEEA), and the Ministry of Transport and Communications of the Republic of Srpska. In the Republic of Srpska, the total of 209 technical inspection stations have been linked to the system. Through this system, the Ministry of Transport and Communications tracks the work of the stations in real time, collects data on the number and type of technical inspections, on the way vehicle inspections are conducted, on time spent on conducting a vehicle inspection, on the work of the station staff, etc. From this single information system, we can obtain data on the number and type of vehicles in the Republic of Srpska and their characteristics, on the number of unroadworthy vehicles in first inspections, extraordinary technical inspections and on the type of detected malfunctions in vehicles. The single information system, apart from being used for the analysis of data relevant for road safety, is used for other analyses, too (assessment of the impact of exhaust gas emission on the environment, public road fee charge within vehicle registration, etc.), [9].

The introduction of this system has greatly improved the quality of vehicle technical inspections in the following areas:

- employment of qualified personnel (traffic engineers and mechanical engineers),
- constant education and training of station personnel;
- single information systems facilitates a full insight into the work of technical inspection stations in real time;
- established database on vehicles and technical inspections necessary for further analyses and improvement of the system and road safety.

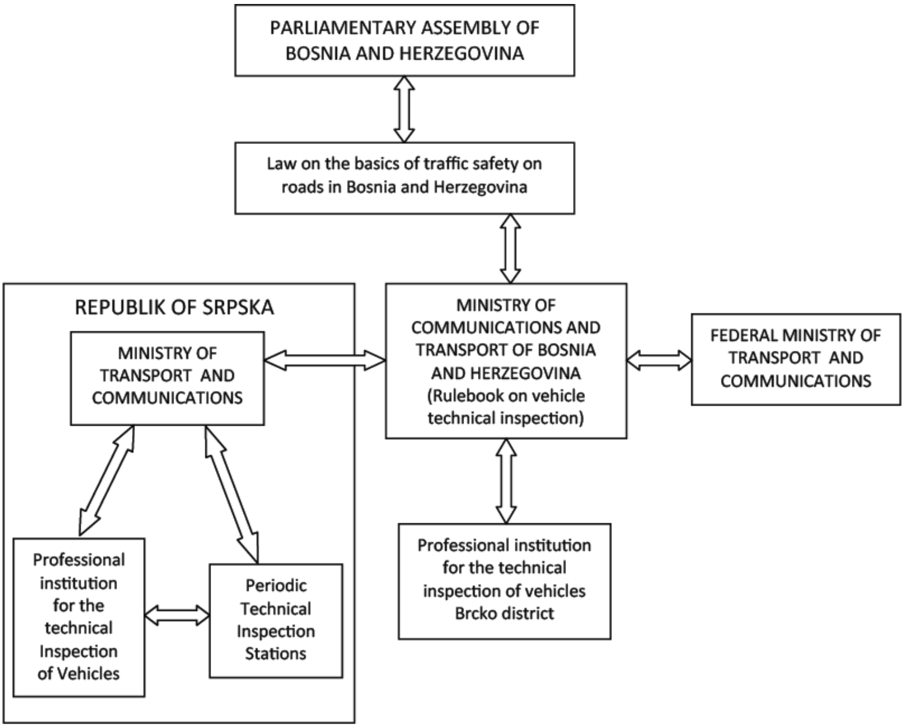

Figure 8 Organizational scheme of activities relating to vehicle technical inspection in the Republic of Srpska

To substantiate the above said, we shall point out that the percentage of vehicles that failed their technical inspection over detected malfunctions increases every year. Table 1 shows data relevant for vehicle inspections in the Republic of Srpska: number of registered vehicles, number of vehicle inspection stations, number of vehicle inspections, number of unroadworthy vehicles identified during inspections, and average vehicle age for each year in the period from 2007 to 2013.

STRATEGIES FOR IMPROVEMENT OF VEHICLE TECHNICAL INSPECTION IN EU

The results of conducted researches and experience gained in individual projects helped in the creation of EU regulations regarding improvement of the vehicle inspection technology.

In October 2009, the EU member states adopted amendments to 2009/40/EC and 2000/30/EC Directives on vehicle technical inspection, [1,8]. Amendments to 2009/40/EC Directive envisaged the control of electronic safety systems to be introduced into vehicle technical inspection. The first step was the MIL lamp check, and the EU member states can also use the “scan tool” devices to control the following systems [2,4,5,10]

- anti-lock braking system (ABS),
- electronic braking system (EBS),
- lectric power steering (EPS),
- electronic stability control (ESC)

- seatbelt system (safety belt load limiter and safety belt pre-tensioner),
- airbag,
- SRS systems.

Table 1 Relevant data for vehicle technical inspections, (Source:Republic of Srpska information system)

Year	2007	2008	2009	2010	2011	2012	2013
No. of registered vehicles	278,339	276,885	274,827	294862	300,278	318,697	330,270
Average vehicle age (years)				16.3	16.6	16.7	16.7
No. of vehicle inspection stations	189	189	181	199	214	208	209
No. of vehicle inspections				330,948	331,264	335,425	350,560
No./percentage of extraordinary inspections				1,989/ 0.6	2,100/ 0.6	2,647/ 0.8	2,821/ 0.8
No./percentage of vehicles that failed inspection				4,376/ 1.3	8,377/ 2.5	21,928 /6.5	42,416 /12.1

Visual inspection of the above systems is already envisaged by 2010/48/EC Directive, stating eliminatory reasons as for all the other vehicle systems inspected during vehicle technical inspection, whilst the application of “scan tools” is not stated as mandatory. It is expected that with the revision of Annex II of the Directive, the control of effectiveness of electronic safety systems by using adequate tools will become mandatory.

A research project named IDELSY (Initiative for Diagnosis of Electronic Systems) is one of important EU research projects with a focus on exploring possibilities for the application of diagnostic tools to control electronic systems in vehicles with safety related functions, [2,4,5,14,15,16]. The seven participating technical inspection organisations were: RWTÜV Fahrzeug GmbH (Essen), TÜV Rheinland Kraftfahrt GmbH (Cologne), TÜV NORD STRASSENVERKEHR GMBH (Hannover), DEKRA Automobil GmbH (Stuttgart), TÜV Süddeutschland (Filderstadt), APPLUS ITEUVE (Barcelona), Vehicle & Operator Services Agency - VOSA (Bristol).

One of the project goals was to explore test procedures (roadworthiness control) for vehicle electronic safety systems by using diagnostic tools (scan tools), whilst roadworthiness control activities would be integrated in the current vehicle technical inspection. Another goal of the research project was to establish proposals for an EU regulation for periodic technical inspections with regard to electronic components.

The research project consisted of three modules, with each module covering predefined activities. Module 1 included collection of data about Europe’s vehicle fleet and capabilities of the existing diagnostic tools, and also a specification of test procedures was designed and a questionnaire for vehicle owners formulated. Module 2 of IDELSY project resulted in the design of test procedures aimed at the electronic components of motor vehicles with safety related functions. The contents of the test procedure and sequence of individual activities are shown in Figure 9. Resulting from a need for new software, IDELSY Manager was developed within Module 2.

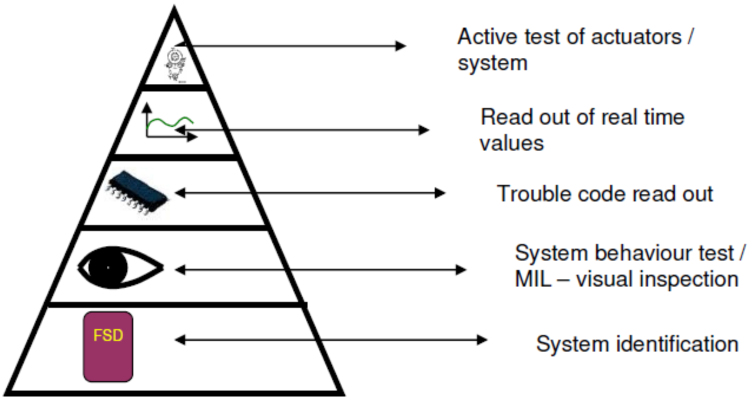

Figure 9 Sequence of individual activities during testing of vehicle electronic systems [17]

Within Module 3, 2.234 vehicles were tested (38 different vehicle manufacturers), vehicle owners were interviewed (questionnaires drafted in Module 1 were filled in), and test results were sorted. The following systems were subject to testing (ABS/ESP, airbag system, engine ECU, and lighting group ECU).

The results obtained from the IDELSY research project justified the initiative for the introduction of control of electronic systems that improve road safety. Only in the first eight months of the project duration, it was detected that around 38,000 vehicles out of the total number of tested vehicles in Germany had defective airbag systems. Recommendations were addressed to vehicle manufacturers, scan tool manufacturers, and to road authorities in charge of the legal regulation of vehicle technical inspections. As to diagnostic tools intended for the control of electronic systems, it was pointed out that the primary goal should be the possibility to achieve a clear identification and communication with all vehicles. Figure 10 shows the structure of the pilot project for technical inspection of vehicle electronic components.

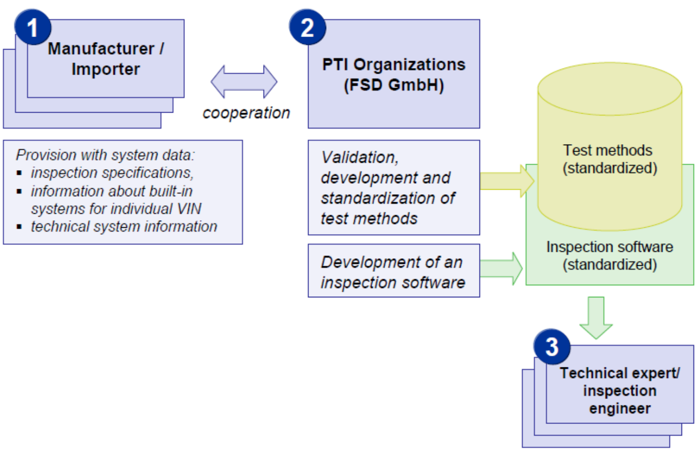

Figure 10 Structure of the pilot project for technical inspection of vehicle electronic components [17]

CONCLUSION

Due to the lack of reliable information, some other factors (usually the human factor) are often stated as the cause of road accidents rather than unroadworthy vehicles. We can therefore assume that the number of unroadworthy vehicles that have caused traffic accidents is much bigger than presented in official statistics. The driver is able to exploit the real potential of any vehicle system only if the system is fully functional.

The improvement of the technology of vehicle technical inspection is a way to seriously contribute to the advancement of active and passive safety of road users. It is therefore necessary that all the systems that improve road safety, including electronic safety systems, be checked within vehicle technical inspection. Full inspection of electronic safety systems within vehicle technical inspection includes, apart from visual inspection, the inspection of functionality and effectiveness of individual systems by means of appropriate tools.

As for the regional level, in order to improve vehicle roadworthiness and thus, road safety, and to create a more favourable environment for the operation of technical inspection stations, it is necessary to:

- work on the improvement of legal regulations and their harmonisation with European and international directives (for example, regional restriction on the number of technical inspection stations, vehicle registration renewal at technical inspection stations, modernisation of the technical inspection technology, etc.),
- conduct continuous preventive and repressive measures through extraordinary technical inspections (inspection of transportation companies' vehicle fleet, etc.),
- work on the improvement of the information system.

REFERENCES

[1] COMMISSION DIRECTIVE 2010/48/EU of 5 July 2010 adapting to technical progress Directive 2009/40/EC of the European Parliament and of the Council on roadworthiness tests for motor vehicles and their trailers, http://www.etrma.org/uploads/Modules/Documentsmanager/20100705-commission-directive-201-48-eu.pdf, access 10/09/ 2011.

[2] Đurić Ž, Škundrić J, Petković S: "Technical Inspection of Electronic Safety Systems in Motor Vehicles", Proceedings, Symposium on Vehicle Technical Inspection in the Republic of Srpska, 2013, University of Banja Luka, 2012, Banja Luka, p. 125-135.

[3] Guide to maintaining roadworthiness Commercial goods and passenger carrying vehicles, Driver and Vehicle Standards Agency, 2014.

[4] http://ec.europa.eu/transport/road_safety/specialist/projects/index_en.htm, access 12/12/2012.

[5] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/321988/guide-to-maintaining-roadworthiness.pdf,

[6] Initiative for Diagnosis of Electronic Systems in Motor Vehicles for PTI - Final Report , European Commission, 31st December 2005. http://ec.europa.eu/transport/roadsafety_library/publications/idelsy_final_report.pdf, access 01/12/ 2011.

[7] International Strategies For Accident Prevention, Dekra Technical Paper 58/05. access 10.02.2010.

[8] Law on the basics of traffic safety on roads in Bosnia and Herzegovina (2006), Official Gazette of the Republic of Srpska, no. 96/06, 57/07, 97/09, 62/10 and 22/13).

[9] Official Journal of the European Union (Commission Directive 2009/40/EU and 2010/48/EU).

[10] Petković S. Kostić N, Đurić Ž," Roadworthiness Tests For Vehicles In The Future - Control Of Vehicle's Electronic Systems", Proceedings 9th International Conference "Road safety in local community", 2014, Serbia, Zajecar, April 9 – 11, 2014.

[11] Petković S, Pešić R, Veinović S: "OBD Vehicle Diagnostics", Bulletin of the Republic of Srpska Maintenance Society, 2008, Banja Luka.

[12] Rulebook on vehicle technical inspection (Official Gazette of the Republic of Srpska, no. 19/07, 95/87, 87/08 and 90/09).

[13] Study on the Future Options for Roadworthiness Enforcement in the European Union Autofore Report, CITA,http://ec.europa.eu/transport/roadsafety_library/publications/autofore_final_report.pdf, access 01/12/ 2011.

[14] World Health Organization,Geneva, 2010. http://www.who.int/gho/road_safety/mortality/traffic_deaths_rates/en/ access 12/08/2013

[15] www.ereg-association.eu, Modernizing Vehicle Inspection – CITA CONFERENCE, access 10/01/ 2012.

[16] www.ereg-association.eu, Modernizing Vehicle Inspection – CITA CONFERENCE. http://www.cita-vehicleinspection.org/, access12/12/2012.

[17] www.esafetysupport.org, Inspection of electronically controlled systems on vehicles according 96/96/EC, access 10/01/2012.

[18] Jöörgrg Van Van Calker, Calker"Inspection of Electronic Components Inspection of Electronic Components within PTI in Germany",Proceedings CITA CONFERENCE, 17 – 20 October, 2006. Hanoi, VIETNAM

FUEL ECONOMY COMPARATIVE ANALYSIS OF CONVENTIONAL AND ULTRACAPACITORS-BASED, PARALLEL HYBRID ELECTRIC POWERTRAINS FOR A TRANSIT BUS

Marko Kitanović, Predrag Mrđa, Slobodan Popović, Nenad Miljić [1]

UDC:629.341;621.431

ABSTRACT: Due to Internal Combustion Engines' (ICE) significant share in global energy demand, primarily through the transportation sector, great efforts are invested in research for solutions that will increase the fuel economy of ICE-powered vehicles. The main objective of the study presented in this paper has been to perform a comparative study of a conventional and a parallel hybrid electric transit bus employing an ultracapacitors-based energy accumulator. A high-fidelity simulation model of the vehicle has been designed in the AMESim multi-domain system analysis software. The conventional powertrain model has been calibrated using data obtained during an acquisition experiment conducted in real-world traffic conditions on a transit bus. This data also served as the basis for defining the driving cycle on which the numerical analyses will be conducted. A simple, sub-optimal control law has been implemented in the hybrid powertrain simulation model. Also, an advanced energy management law based on Dynamic Programming has been derived to assess the ultimate fuel economy improvement potential of the hybrid solution and to make design decisions. Initial study shows that considerable fuel consumption reduction in excess of 30% could be achieved by implementing a regenerative hybrid system employing an ultracapacitor-based accumulator.

KEY WORDS: Simulation, Transit Bus, Ultracapacitors, Dynamic Programming, Internal Combustion Engines

KOMPARATIVNA ANALIZA POTROŠNJE GORIVA KONVENCIONALNOG I HIBRIDNOG GRADSKOG AUTOBUSA SA PARALELNIM HIBRIDNIM POGONSKIM SISTEMOM

REZIME: Usled značajnog udela motora SUS u globalnoj potrošnji energije, prevashodno putem transportnog sektora, veliki istraživački napori ulažu se u povećanje energetske efikasnosti vozila. U radu su prikazani rezultati komparativne analize potrošnje goriva konvencionalnog i gradskog autobusa sa hibridnim pogonskim sistemom koji koristi ultrakondenzatore za skladištenje energije. Za potrebe ovog istraživanja realizovan je simulacioni model u AMESim okruženju. Model konvencionalnog pogonskog sistema kalibrisan je prema podacima dobijenim u toku eksperimenta na gradskom autobusu u realnim eksploatacionim uslovima. Podaci dobijeni akvizicijom poslužili su i za definisanje relevantnog voznog ciklusa koji je korišćen za numeričke analize opisane u radu. Prikazani su rezultati simulacije dobijeni korišćenjem jednostavnog zakona upravljanja radom hibridnog sistema. Takođe, u radu su prikazani metodologija i rezultati rešavanja optimalnog kontrolnog problema metodom dinamičkog programiranja. Prikazane su vrednosti maksimalno moguće uštede u potrošnji goriva kao i optimalnih projektnih parametara na osnovu izvedenog rešenja optimalnog upravljanja radom hibridnog sistema.

[1] *Received: June 2014, Accepted August 2014, Available on line November 2014*

Zaključak jeste da su implementacijom hibridnog pogonskog sistema na bazi ultrakondenzatora moguće uštede u potrošnji goriva i do 30%.

KLJUČNE REČI: simulacija, gradski autobus, ultrakondenzatori, dinamičko programiranje, motori SUS

FUEL ECONOMY COMPARATIVE ANALYSIS OF CONVENTIONAL AND ULTRACAPACITORS-BASED, PARALLEL HYBRID ELECTRIC POWERTRAINS FOR A TRANSIT BUS

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UDC:629.341

INTRODUCTION

Rising fuel prices and increasing awareness of environmental issues place greater emphasis on the quest for solutions that improve vehicle fuel economy and reduce harmful emissions. One of the many possible directions in that regard, but perhaps the most promising, is powertrain hybridization. Achieving improved fuel economy, lower emissions and a relatively low price without incurring penalties in performance, safety, reliability, and other vehicle-related aspects represents a great challenge for the automotive industry. For accommodating the hybrid powertrain demands of heavy vehicles, particularly those undergoing frequent deceleration and acceleration phases, the best solutions are those that can sustain very high power levels, such as the hydraulic hybrid or the ultracapacitors-based electric hybrid systems.

The numerical investigation, whose results will be presented in this paper, relies on model-based design tools. Modeling of vehicle and propulsion systems has been carried out using the LMS Imagine.Lab AMESim 1D multi-physics system simulation environment. This platform provides a graphical programming interface and an extensive set of validated components organized in different libraries for modeling and analyzing system performance.

An experiment has been conducted on a transit bus circulating in real traffic and occupancy conditions to assess the circumstances encountered in this particular type of transportation and in order to obtain the real driving cycle and powertrain parameters necessary for conducting virtual analyses involving hybrid solutions. Data acquired during this experiment has been of crucial importance; effectively allowing us to calibrate the parameters of the propulsion components in AMESim. Precisely, submodels of components such as the automatic gearbox, torque converter, internal combustion engine, among others, have been set up and calibrated.

By successfully transferring the real-world physical conditions into computer code, a vast array of numerical study possibilities has been opened. In this paper, the results of a simulation involving the use of an ultracapacitors-based hybrid electric powertrain system are laid out. Also, considerations regarding the optimal control of such a hybrid solution are presented, with an emphasis on optimal control theory and in particular the Dynamic

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Programming principle. This principle has been applied on a simplified powertrain model in Mathworks MATLAB software in order to derive an optimal control trajectory and to assess the ultimate fuel economy improvement potential for the vehicle and the driving cycle in question. A Dynamic Programming model of a hybrid powertrain can be used to great effect for determining the optimal component size (such as the energy accumulator capacity, for example) because an optimal control is obtained for every single component parameter that can be changed. Design decisions regarding the optimal gear ratio between the electric motor/generator and the gearbox and the number of ultracapacitors modules have been made using this Dynamic Programming (DPM) model.

DATA ACQUISITION

In the following paragraphs, the experiment conducted on a transit bus circulating in real traffic and occupancy conditions is described. Furthermore, the results of a data analysis on data obtained during this experiment, which are subsequently used as input for the simulation models, are presented in this section of the article.

EXPERIMENTAL SETUP

Acquiring the real driving cycle in differing occupancy and traffic conditions, along with drivetrain and powertrain parameters is of crucial importance for predicting achievable fuel economy improvements. The experiment was conducted on an Ikarbus IK206 vehicle, equipped with a MAN D2066 LUH 11 engine (10.5 dm3, 6-cylinder, turbocharged diesel engine) and Voith 864.5 automatic transmission, circulating on line 83 of the public transportation system in Belgrade.

An autonomous data acquisition system based on National Instrument’s CompactRIO hardware platform and LabVIEW software has been designed for this purpose. The powertrain parameters were acquired by accessing the vehicle’s J1939 CAN bus by means of a high-speed NI 9853 CAN module. The raw network stream has been logged and afterwards processed according to the SAE J1939 standard [9]. In order to obtain the GPS coordinates of the driving cycle, which are needed for determining the road slope, a Garmin GPS 18x 5 Hz receiver streaming NMEA messages was used. Suspension system pressure sensors have also been installed in order to log the vehicle mass during the experiment.

This experiment has been conducted for the duration of several weeks, during which a vast amount of highly valuable data has been collected. Out of a vast number of recorded driving cycles, only one was chosen that will serve as the reference cycle for which numerical analyses will be conducted. Information about the chosen driving cycle, along with acceleration and vehicle mass distribution can be found in Figures 1 and 2. The recorded driving cycle vehicle speed is shown in Figure 3.

POWERTRAIN PARAMETERS IDENTIFICATION

Certain requirements shall be met if one is considering a successful transition from real into the world of virtual simulation. If the scope of the simulation effort encompasses fuel efficiency considerations, perhaps the most important parameters are those related to engine fuel consumption and torque maps. By analyzing and processing the acquired data channels, specifically those included into Electronic Engine Controller 1 (Parameter Group Name EEC1) and Electronic Engine Controller 3 (PGN EEC3) J1939 messages, maximum/minimum torque limits (Figure 4) and brake specific fuel consumption maps have been arrived at.

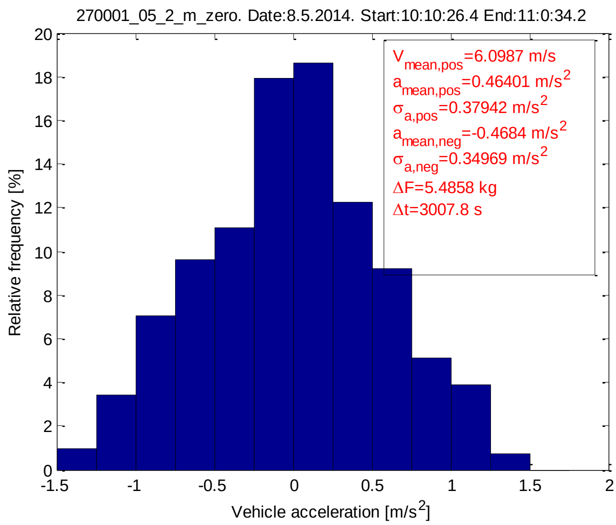

Figure 1 Driving cycle acceleration distribution

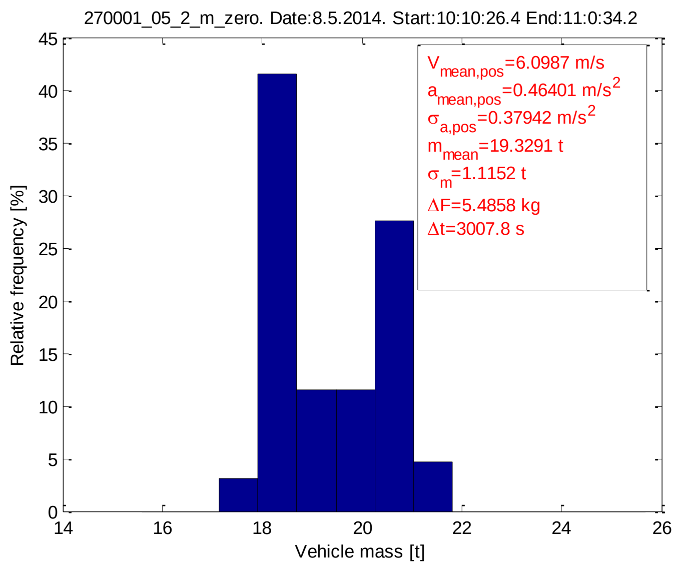

Figure 2 Vehicle mass distribution

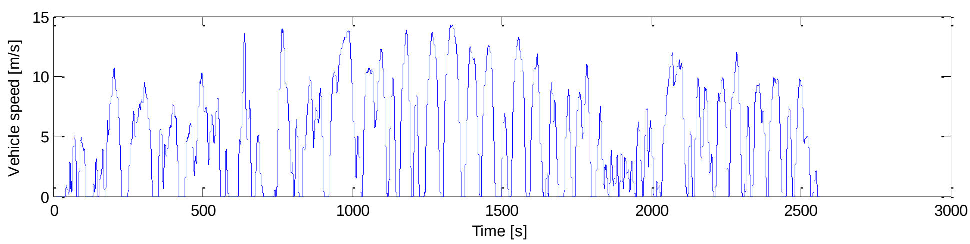

Figure 3 Driving cycle vehicle speed

A MATLAB script has been written to extract data according to a predefined engine operating points map. By singling out and collecting values of volumetric fuel flow rate associated with certain operating regimes into arrays, and subsequently processing them by eliminating outliers (using a bisquare robust, locally weighted linear regression model), a sound set of fuel flow rate values could be obtained. In order to form the Brake Specific Fuel Consumption (BSFC) map for the entire operating range of the engine (Figure 5), this set of values is further used as an input to a Kriging interpolation algorithm (DACE for Matlab toolbox) [5].

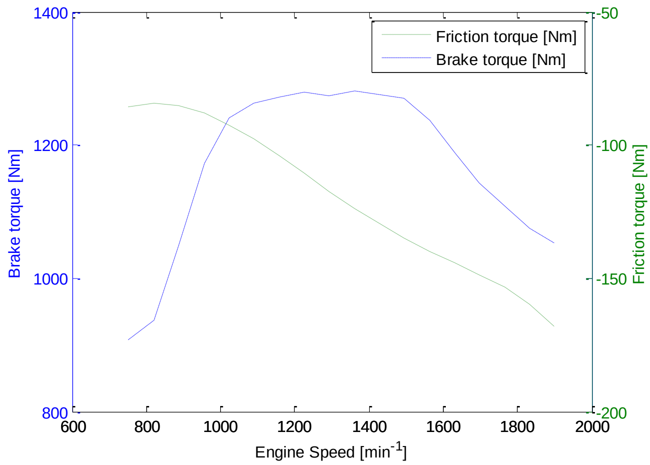

Figure 4 Max. engine brake torque and friction torque

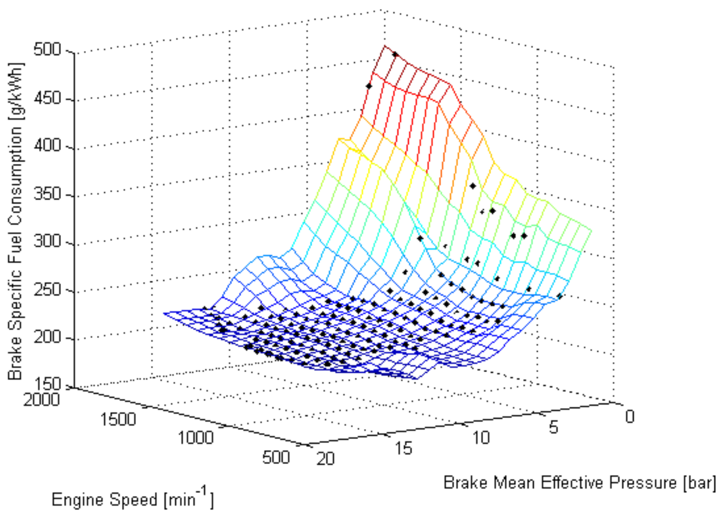

Figure 5 Brake Specific Fuel Consumption (BSFC) map

Another set of identification procedures has been performed to obtain the characteristics of the automatic gearbox torque converter. The dependence of the torque converter torque ratio on the speed ratio, along with the capacity factor have been identified and implemented into the simulation models.

The road slope has been calculated using the Digital Elevation Model (DEM) data files from the Shuttle Radar Topography Mission [8]. These represent the most reliable and accurate widely-accessible elevation data files currently available. Due to the great sensitivity of the road slope on the force required to sustain a given vehicle speed, certain provisions regarding the smoothness of the elevation profile along the route had to be taken. For this aim, the GPS coordinates for 200 intervals of the distance from one part of the city to the other were averaged to obtain 200 values of elevation. This elevation data was subsequently smoothed by means of a cubic smoothing spline algorithm and the obtained model was further differentiated to finally obtain the road slope (Figure 6).

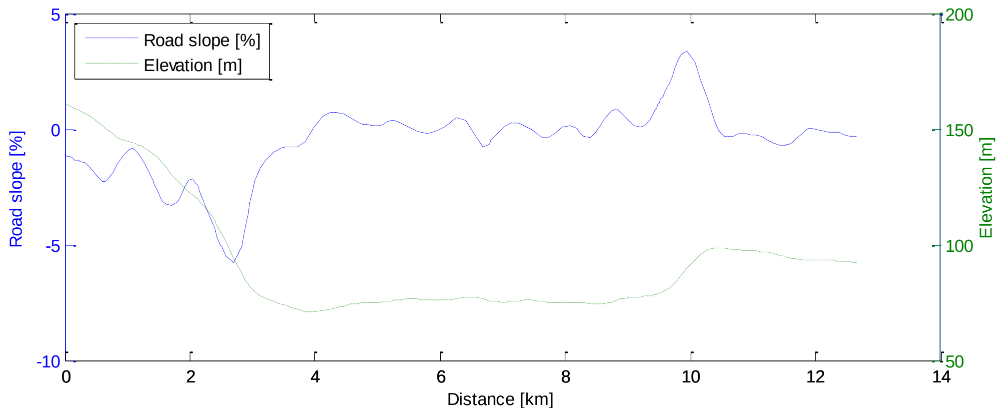

Figure 6 Driving cycle elevation and road slope profiles

SIMULATION ANALYSES

This section of the article deals with the simulation analyses that are set up according to parameters and driving cycle details presented in the preceding paragraphs. First, an overview of the most important submodels and corresponding equations that are used in the LMS Imagine.Lab AMESim simulation environment will be given. Results of a calibration procedure of the simulation model will also be presented before moving to a discussion of the results of a comparative analysis of hybrid and conventional powertrains using a simple, implementable control law. At the end of this part, a Dynamic Programming model of the transit bus hybrid powertrain will be presented, along with results showing the ultimate potential of the hybrid solution considered in this study.

CONVENTIONAL TRANSIT BUS POWERTRAIN MODEL

A simulation model of a conventional transit bus powertrain system has been set up in AMESim, which was used to compare the results of the hybrid powertrain system to.

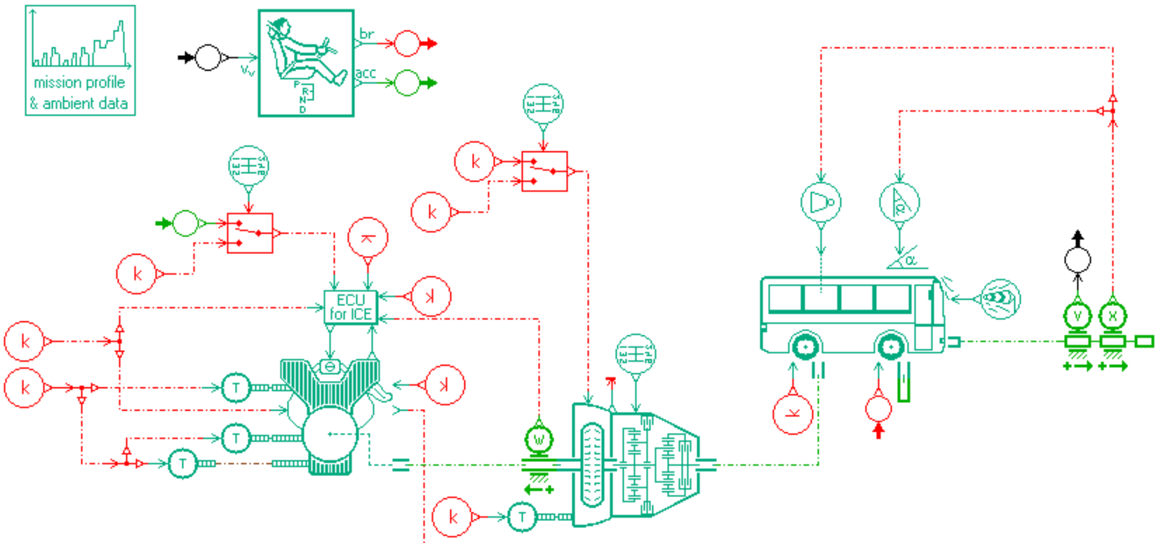

Figure 7 AMESim model of a conventional transit bus powertrain system

The bus component is responsible for evaluating the acceleration to be integrated by the AMESim solver in order to obtain the actual vehicle velocity [1]:

$$\frac{dv_{veh}}{dt} = \frac{1}{m_{veh}}\left[F_{dr} - \left(F_b + F_{res}\right)\cdot C_{stat}\right] \quad (1)$$

where C_{stat} is the stiction coefficient, which is greater than one only when the vehicle is stationary (1.2 in this study). The driving force F_{dr} is calculated by means of the following equation:

$$F_{dr} = \left(T_2 + T_4\right)/\, R_w \quad (2)$$

where T_2 and T_4 are input torques at ports 2 and 4 (rear and front axles) of the bus and R_w is the wheel radius.

In addition to raising the kinetic and potential energy of the vehicle, part of the energy from the propulsion system is used to accelerate rotating parts of the drivetrain. The inertial force of the vehicle wheels is calculated using the following equation [3]:

$$F_w = \frac{\Theta_w}{R_w^2}\cdot\frac{dv_{veh}}{dt} \quad (3)$$

Considering the case where wheel slip is not accounted for, the contribution of the wheels to the vehicle overall inertia is given by

$$m_w = \frac{\Theta_w}{R_w^2} \quad (4)$$

where Θ_w is the wheels inertia and equals 120 kgm^2 in this simulation study.

The braking force is similarly obtained:

$$F_b = \left(T_{b,front} + T_{b,rear}\right)/\, R_w \quad (5)$$

The resistance force is evaluated using the equation taking into account the climbing resistance, aerodynamic drag and rolling friction:

$$F_{res} = F_{cl} + F_{aero} + F_{roll} = \left(m_{veh} \cdot g \cdot \sin\left[\arctan\left(0.01 \cdot \alpha\right)\right]\right) + \\ + \left(\frac{1}{2} \cdot \rho_{air} \cdot c_x \cdot S \cdot v_{veh}^2\right) + m_{veh} \cdot g \cdot \left(f + k \cdot v + w \cdot v^2\right) \tag{6}$$

where α is the road slope in %, S is the vehicle frontal area, f is the constant (Coulomb) rolling friction coefficient, k is the rolling friction coefficient proportional to vehicle speed (viscous coefficient) and w to vehicle speed squared (windage).

The propulsion torque is controlled by the driver component, which is a PID controller taking the difference between the actual and desired vehicle speed to form an acceleration command supplied to the engine ECU. After the controller unit reacts and sends an appropriate load signal to the engine, the output torque is multiplied in the gearbox and transferred to the bus. On the other hand, the braking command, also initially formed in the driver component, is sent directly to the front axle of the bus model.

Gear shifting occurrences have been transferred from collected data into the simulation model. It should be noted that the lockup clutch in the torque converter engages in all gears except the first.

MODEL CALIBRATION

For making sure the conditions are successfully transferred and the dynamic behavior of the most important variables are in agreement with the ones that were acquired during the physical experiment, a calibration procedure was set up. An optimization procedure in the Design Exploration module in AMESim was used to calibrate the rolling friction parameters so that the sum of the squared difference between the simulated and the acquired mass of fuel consumed along the route was minimized. A genetic algorithm was used to that effect because it converges to the global minimum. The population size was 100, reproduction ratio being 60%. The number of generation was 20 with mutation probability of 10% and an amplitude of 0.6. The resulting rolling friction parameters are presented in Table 1.

Table 1 Results of the calibration process

Rolling friction Coulomb coefficient	f=0.01643
Rolling friction viscous coefficient	k=0.0003147 1/(m/s)
Rolling friction windage coefficient	$w=1.515 \cdot 10^{-5}$ $1/(m/s)^2$

The recorded and simulated cumulative fuel consumption curves are shown in Figure 8. A satisfactory matching has been achieved, even though a slight deviation appears at about the 950 s mark. It should be noted that the calibration procedure has been performed for a limited range of time from 0 to 2525 s because the remaining part of the driving cycle includes only stationary vehicle state with engine turned off.

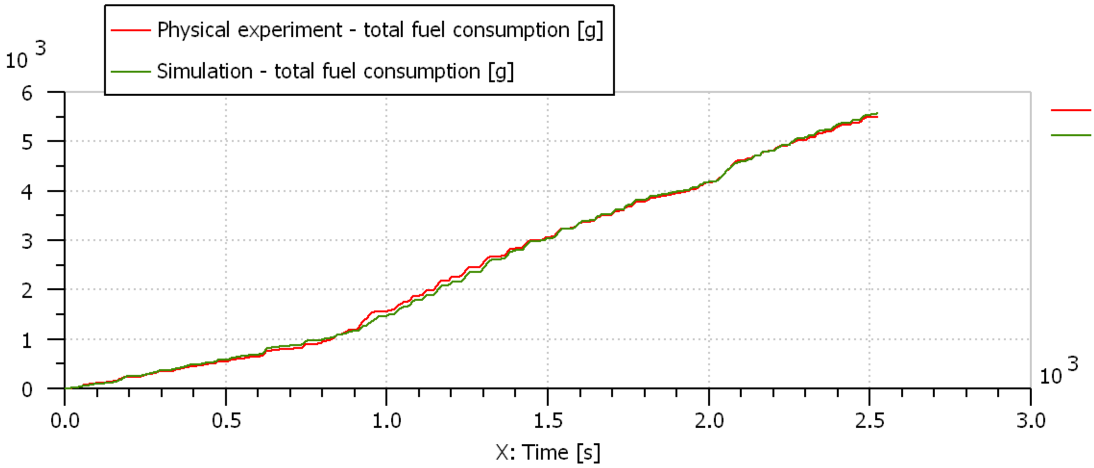

Figure 8 Cumulative fuel consumption matching

HYBRID TRANSIT BUS POWERTRAIN MODE

lA parallel hybrid transit bus powertrain system has also been modeled in AMESim. It includes a 175 kW electric motor/generator (max. torque 500 Nm up to 3000 RPM, max. power at 4400 RPM) placed between the torque converter and the gearbox through a 3.5 reduction gear. Several ultracapacitor (UC) configurations are used as energy accumulators in this hybrid electric system. They are based on the Maxwell 125 V transportation module [6] (BMOD0063 P125, see Table 2). The energy accumulator is coupled to the electric machine by means of an electric power converter module that adjusts the variable ultracapacitors voltage to a given motor/generator voltage (set to a constant value of 650 V in this study, with constant conversion efficiency in both directions of 90%).

Table 2 Electrical characteristics of ultracapacitor modules configurations

Ultracapacitor configuration	Capacitance [F]	ESR [mΩ]	Rated voltage [V]	Stored energy (50%-100% SOC) [MJ]
1 module	63	18	125	0.37
2 modules/series	31.5	36	250	0.74
3 modules/series	21	54	375	1.11
4 modules/series	15.75	72	500	1.48

A simple, implementable, sub-optimal control law is used for controlling the engine and motor loads during traction phases. Indeed, for every given driver acceleration output the signal that is sent to the motor is first multiplied by three while the signal sent to the internal combustion engine is sent as is. This has the effect of achieving a variable load splitting ratio, as seen in Figure 9. The motor is contributing to the overall vehicle traction until the State of Charge (SOC) of the ultracapacitor module falls below 50%.

During braking phases, the generator is used to decelerate the vehicle and recuperate as much energy as possible, unless the recuperation isn't possible. If the deceleration achieved by the generator is not enough, friction brakes are applied.

The results of the numerical analysis are given in Table 3. Fuel consumption has been decreased by 16.8% (when using 4 ultracapacitor modules) compared to the conventional vehicle. It can be seen that no significant fuel consumption reduction can be achieved by increasing the number of ultracapacitor modules. Indeed, by doubling the effective energy storage capacity, only an additional 0.68% of fuel can be saved.

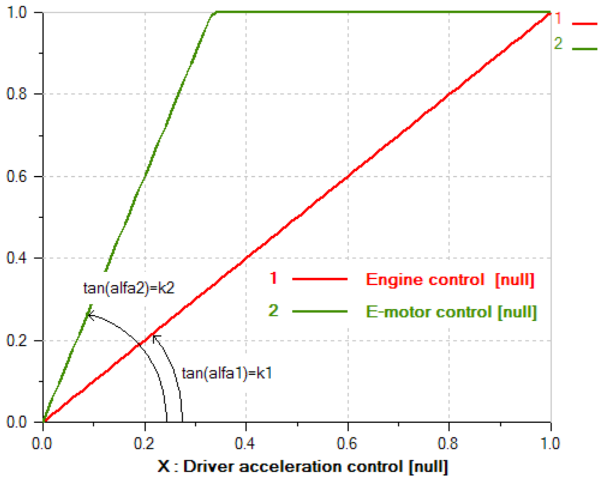

Figure 9 Traction control law [1]

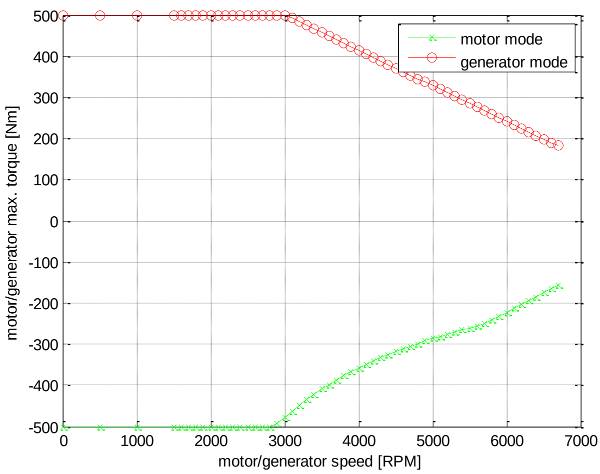

Figure 10 Motor/generator max. torque

Table 3 Fuel consumption for the conventional and hybrid transit bus powertrains

	Reference run (conventional powertrain)	Hybrid electric configuration (number of ultracapacitor modules)		
		2	3	4
Absolute mass of fuel consumed [g]	5501.457	4613.17	4590.026	4575.358

Fuel consumption decrease [%]	-	16.15	16.57	16.83

The reasons for such insignificant fuel economy improvements with increasing energy capacities can be seen by taking a look at Figure 11, depicting the energy accumulator state of charge (SOC) during the simulation. The SOC of the accumulator with the least amount of energy capacity (with 2 ultracapacitors) reaches 100% only in 4 occurrences. The accumulators with 3 and 4 UC modules never reach 100% SOC. It can be said that the increased energy storage capacity is not being efficiently used.

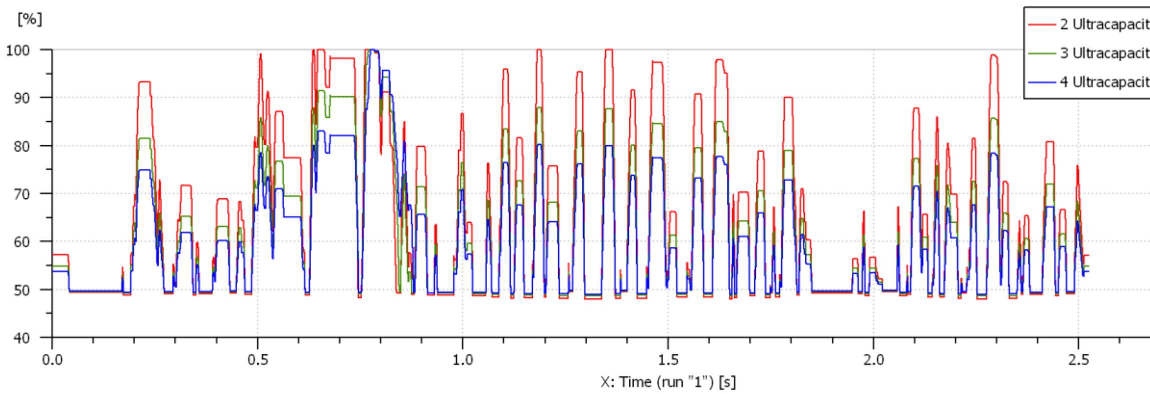

Figure 11 Cumulative fuel consumption matching

By looking solely at the fuel consumption figures of the conventional and hybrid powertrain systems, one would not be justified in choosing a configuration with more than 2 UC modules. However, considering the difficulties associated with performing efficient, high-ratio voltage amplification, the most desirable ultracapacitor configurations are those characterized by a high number of modules connected in series. In these cases, even when the SOC falls to the low limit of 50%, the voltage multiplication is small enough to ensure an efficient power conversion. Also, peak and mean current levels at the interface between the UC modules and the electric power converter module are decreased by increasing the number of ultracapacitors, thus favorably impacting their lifespan.

DYNAMIC PROGRAMMING MODEL OF THE HYBRID TRANSIT BUS POWERTRAIN

For the purpose of evaluating the ultimate fuel economy performance of the hybrid configuration described in the preceding subsections, a dynamic programming approach to obtaining the control law that minimizes the amount of fuel consumed has been employed in this study. Dynamic programming relies on the principle of optimality, which states that [2] "An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision."

By decomposing a control problem into segments or sub-problems, an optimal decision can be discovered at each stage starting from the end and moving toward the initial start time. By defining the desired final system state, a dynamic programming algorithm starts with evaluating the optimal decision at the stage preceding the final stage that will result in the system reaching this final state at minimal cost. This is done by discretizing the state space which results in a time-state space grid with nodes at which the cost is evaluated by sweeping the admissible control values, subject to state constraints. By proceeding backwards, an optimal control decision can be stated for each stage-state combination that will bring the system from the current stage-state point to the desired final state at minimal cost. By ultimately reaching the initial time stage, the cost-to-go matrix, and optimal control matrices are obtained, representing respectively the cost and optimal control decisions for each admissible stage-state combination. Mathematically, this can be stated through a recurrence relation [4]:

$$J^*_{N-K,N}\left(\vec{x}(N-K)\right) = \min_{u(N-K)} \left\{ \begin{array}{l} g_D\left(\vec{x}(N-K), \vec{u}(N-K)\right) + \\ + J^*_{N-(K-1),N}\left(\vec{a}_D\left(\vec{x}(N-K), \vec{u}(N-K)\right)\right) \end{array} \right\} \quad (7)$$

By knowing , the optimal cost at (K-1) stage, the optimal cost for the K stage can be determined, along with its corresponding control.

In this study, the torque ratio between the engine and electric motor during the traction phases, and the torque ratio between the electric generator and the friction brakes during braking phases is the actual control variable. The hybrid powertrain system is described in the Dynamic Programming (DPM) model by a single, discretized state equation representing the state of charge of the ultracapacitors modules.

A generic MATLAB implementation of the dynamic programming algorithm has been used in this study [7]. All the relevant data obtained during the physical experiment and identified afterwards has been transferred into MATLAB to be used by this DPM algorithm. The vehicle resistive forces models, driving cycle data (vehicle speed, acceleration, road slope, vehicle mass and selected gear), electric motor/generator maps, engine BSFC map, transmission characteristics, and ultracapacitors-based energy accumulator models have been implemented into a MATLAB function that is evaluated by the DPM routine.

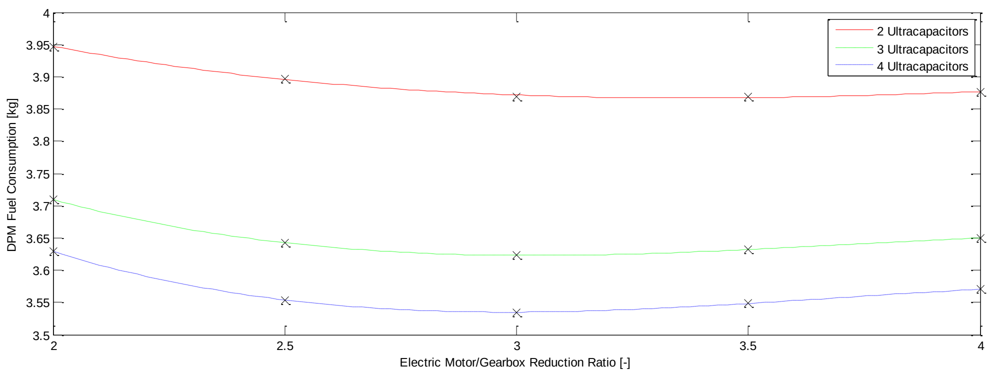

Figure 12 DPM fuel consumption results – accumulator capacity, reduction ratio parameters sweep

Table 4 Fuel consumption comparison between the conventional and DPM hybrid transit bus models (3 UC)

	Reference run (conventional powertrain)	DPM Hybrid electric configuration (reduction ratio) for 3 UC modules				
		2	2.5	3	3.5	4

Absolute mass of fuel consumed [g]	5501.457	3709.7	3642.7	3622.9	3632.2	3650.2
Fuel consumption decrease [%]	-	32.6	33.8	34.1	34.0	33.7

The final state has been fixed to the accumulator SOC of 0.65. The admissible state values range from 0.5 to 1.0 and are discretized evenly into 101 total values. The admissible control values range from 0 to 1 and are discretized also evenly into 101 total values. The simulation time step has been set to a relatively low 0.2 s in order to preserve the shape and smoothness of the vehicle acceleration data that has a high influence on the total vehicle resistive force and to obtain more accurate fuel consumption results.

The results of the DPM simulation are shown in Figure 12 for a range of reduction gear ratio values and 3 values of total accumulator energy capacities (equal to 2, 3 and 4 UC modules, with electrical characteristics as shown in Table 2). It can be seen that the absolute amounts of fuel consumed are significantly lower than in the case of a simple control used in the AMESim simulation, and up to 34% of fuel can be saved using three UC modules. As can be seen in Figure 13, the range of SOC variation in DPM simulation is greater than in the corresponding simulation case that uses a far simpler control algorithm. The optimal reduction gear ratio has been found to be approximately 3, with the slopes of the DPM fuel consumption-gear ratio curves increasing with additional UC modules around this value.

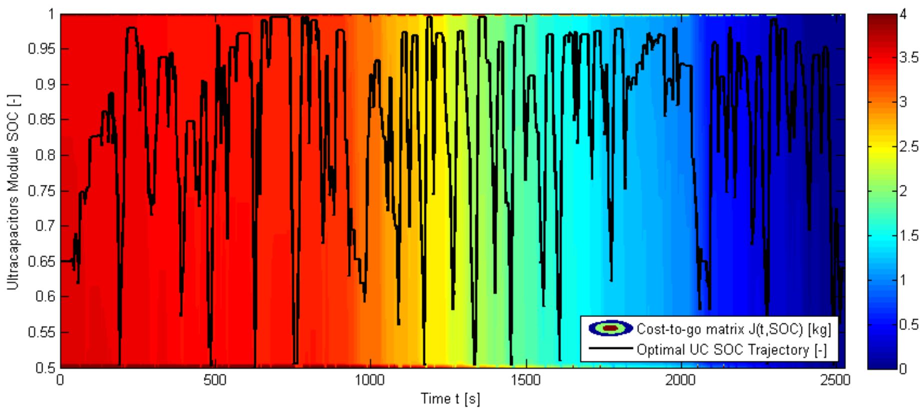

Figure 13 Cost-to-go matrix visualization with optimal SOC trajectory (reduction ratio=3, number of UC modules=3)

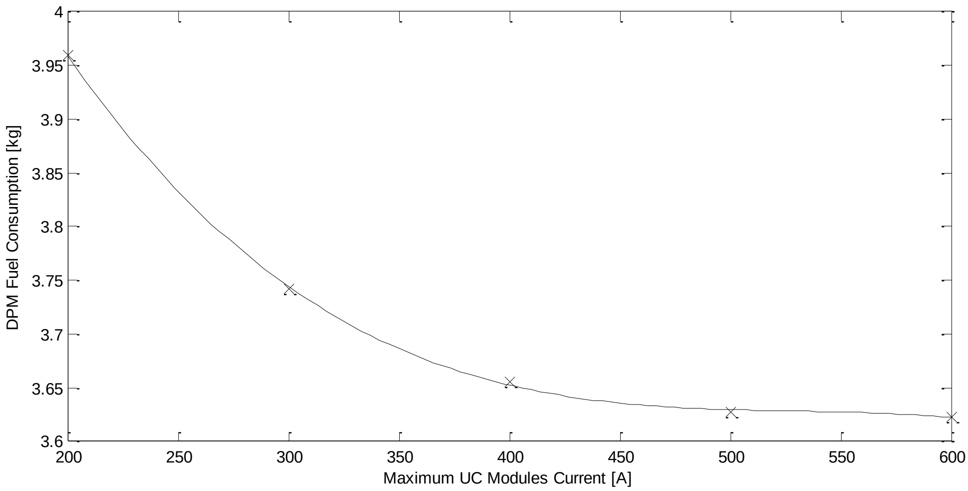

Figure 14 DPM fuel consumption results – maximum allowable UC current sweep

The DPM simulation can also be used to obtain the optimal values of parameters that have a pronounced effect on components lifespan, such as the maximum allowable ultracapacitor current. The results of such a calculation is shown in Figure 14, for the gear ratio value of 3 and 3 UC modules. By increasing the allowable absolute current levels, the fuel consumption is decreased but a compromise must be made with regard to acceptable UC lifespan.

CONCLUSION

A transit bus powertrain system has been modeled and calibrated in the AMESim simulation software environment based on data collected during a data acquisition experiment conducted on a vehicle circulating in real traffic and occupancy conditions. This calibrated model has subsequently been used to form a hybrid powertrain simulation model in AMESim with a simple, implementable control law for determining the fuel economy improvements of an ultracapacitors-based parallel hybrid electric solution. It was shown that moderate fuel reduction of approximately 16% could be achieved using a very simple control algorithm. For determining the ultimate fuel economy improvements achievable using this hybrid solution, a Dynamic Programming approach to solving the optimal control problem has been used. Using this approach, it has been determined that a fuel consumption decrease of 36% percent is the ultimate achievable goal. This approach can render making certain design decisions with regard to their effect on the fuel economy and lifespan relatively easy, such as in the case of determining the achievable fuel economy improvement with different absolute maximum values of UC currents. This data can be used to make a sound choice in the allowable current levels based on the optimal compromise between the lifespan of a component and fuel savings.

It should also be noted that a DPM algorithm is not implementable, meaning that it cannot be used on a real vehicle, due to reasons that have to do with its contingency on conditions that will be experienced in the future. That is why this approach can only be used for determining the ultimate achievable performance of a set criterion and as a reference which certain sub-optimal, implementable control laws can be compared to. Further work into this matter will include a research into the implementable control algorithms best suited for the case presented in this article..

REFERENCES

[1] AMESim Rev 13 SL2 IFP Drive documentation

[2] Bellman, R. E., Dreyfus, S. E.: “Applied Dynamic Programming”, Princeton University Press, 1962,

[3] Guzzella, L., Sciarretta, A.: “Vehicle Propulsion systems - Introduction to Modeling and Optimization”, 2nd edition, Springer, 2007,

[4] Kirk, D. E.: “Optimal Control Theory: An Introduction”, Dover Publications, 2004,

[5] Lophaven, S. N., Nielsen, H. B., Søndergaard, J.: “DACE - A Matlab Kriging Toolbox”, Technical Report IMM-TR-2002-12, Technical University of Denmark, 2002,

[6] Maxwell Technologies, Ultracapacitor 125 Volt Heavy Transportation Modules, from http://www.maxwell.com/products/ultracapacitors/products/125v-tran-modules,

[7] Sundstrom, O., Guzzella, L.: "A generic dynamic programming Matlab function", Control Applications, (CCA) & Intelligent Control, (ISIC), 2009 IEEE, 2009, St. Petersburg, pp.1625,1630,

[8] U.S. Geological Survey, Shuttle Radar Topography Mission, 3 Arc Second N44E020, Version 2.1. Available: http://dds.cr.usgs.gov/srtm/,

[9] "Vehicle Application Layer", SAE J1939/71_200412, Truck Bus Control And Communications Network Committee, Society of Automotive Engineers, 2004,

APPLICATION OF HYDROGEN AS ALTERNATIVE FUEL FOR PROPULSION SYSTEMS IN CITY BUSES – OVERVIEW -

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UDC:629.341;621.6.028

ABSTRACT: Fuel can be dangerous if handled improperly. Gasoline and diesel are potentially dangerous fuels, but over time we are learned to use them safely. The same is true with liquefied petroleum gas and natural gas. The hydrogen is suitable as a fuel for vehicles powered with both, internal combustion engines or indirectly for electric engines inside of fuel cell propulsion systems, too.

The problems associated with the production and storage of hydrogen currently limits the application of pure hydrogen as engine fuel in vehicles. This paper represents our designing proposition of a low-floor city bus for hydrogen power.

For application inside of low-floor city buses, hydrogen cylinders have to be installed on the roof for reasons of space. In addition, regarding to the lack of available information, the paper demonstrates an overview about safety regulations for vehicles with regard to the installation of specific components in hydrogen fuel line.

KEY WORDS: Hydrogen buses, Safe vehicle, Emission, City transport

PRIMENA VODONIKA KAO ALTERNATIVNOG GORIVA POGONSKIH SISTEMA GRADSKIH AUTOBUSA – PREGLED -

REZIME: Gorivo može biti opasno ako se njime rukuje nepravilno. Benzin i dizel su potencijalno opasna goriva, ali smo vremenom naučili da ih bezbedno koristimo. Slično važi i za tečni naftni gas i prirodni gas. Vodonik je dobro gorivo za vozila, bilo da se radi o direktnoj primeni u motoru sa unutrašnjim sagorevanjem ili indirektno za napajanje elektro motore posredstvom gorivih ćelija i električnog napona.

Problemi u vezi proizvodnje i skladištenja vodonika trenutno limitiraju njegovu primenu kao gorivo u motornim vozilima. U okviru rada je prikazan predlog koncepcije niskopodnog gradskog autobusa sa pogonom na vodonik.

U skladu sa raspoloživim prostorom, rezervoari za skladištenje vodonika se obično ugrađuju na krovu gradskog niskopodnog autobusa. Dodatno, u skladu sa nedostatkom raspoloživih informacija, u radu je prikazan pregled propisa u vezi bezbednosti ugradnje specifičnih delova instalacije za snabdevanje vodonikom.

KLJUČNE REČI: Autobusi na vodonik, bezbedno vozilo, Emisija, gradski saobraćaj

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APPLICATION OF HYDROGEN AS ALTERNATIVE FUEL FOR PROPULSION SYSTEMS IN CITY BUSES OVERVIEW

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UDC:629.341;621.6.028

INTRODUCTION

For almost forty years now, automotive engineers from all over the world have been engaged in the intensive researches to find a technically and economically viable alternative to gasoline or diesel fuels. Research efforts in this domain begin back in the late Sixties and were spurred on by the oil crisis in 1973. At the time, with development work on alternative solutions still in its infancy, the industrial nations' economic dependency on oil was made eminently clear [4]. Today, the availability of improved and alternative propulsion systems is not only a question of ensuring economic and political independence. The main concern now is to conserve available resources and reduce carbon dioxide (CO2) emissions from the combustion of fossil fuels, alleviating the associated environmental problems.

Eco-friendly transport is a fundamental condition for sustainable prosperity all over the world. Transport provides the mobility of citizens and contributes to the growth of employment and global exports. The European transport industry as example represents about 6.3% of the Union's GDP and employs nearly 13 million people. Transport accounts for about 63% of oil consumption and 29% of all CO2 emissions [4].

Nowadays research aims to strengthen the competitiveness of transport and to develop a better transport system for the benefit of all. Related to previous facts, after confirmed experience with natural gas powered buses, we decided to start our researches in domain of hydrogen propulsion systems for city buses, too. According to the latter we would like to thank you to any readers and colleagues to understanding our starting effort about.

HYDROGEN AS FUEL FOR MOTOR VEHICLES

Over 90% of the universe is made of hydrogen. It is lightest chemical element (1.00794 $g \cdot mol^{-1}$), lighter then helium. At room temperature, hydrogen is a colourless and odourless gas. Hydrogen has high energy content per weight, nearly three times as much as gasoline, but the energy density per volume is low at standard conditions, so it needs to be stored under pressure or as a cryogenic liquid. Difference in the density of energy of different fuels which used for motor vehicle is presented on the Figure 7 [4].

All gases are good fuels for Otto engines: a mixture with air is high quality and ready for complete combustion, the work of engine is economical, with lower exhaust emissions and extended oil and engine life. Hydrogen requires a small amount of energy to ignite. It has a wide flammability range; it can burn when it makes up 4 to 74% of the air by volume. It burns with a pale blue, almost-invisible flame [4].

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The environmental benefit of using hydrogen as fuel for motor vehicles is the reduction of exhaust gases. Combustion of hydrogen does not produce CO_2, or sulphur emissions. Compared to the exhaust emission of equivalent diesel engine in city bus, as example, nitrogen oxide (NOx) and hydro carbon (HC) emissions are 80% lower, carbon monoxide (CO) emission is eliminated, and there are around zero particulates matter (PM), Figure 1. Second example is a fuel cell, inside of the hydrogen reacts with Oxygen to make water and electricity [1,4].

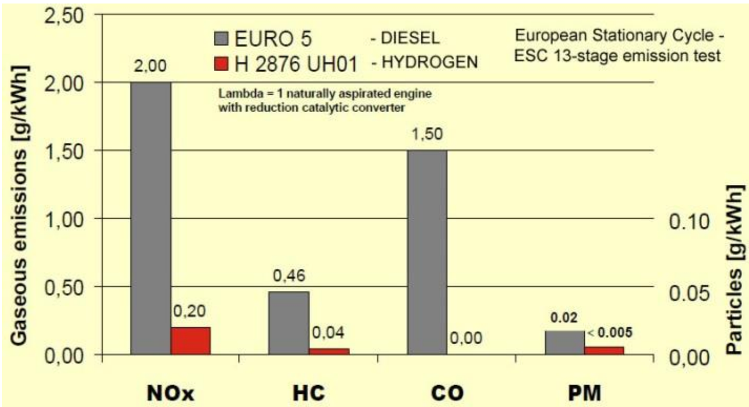


Figure 1: Exhaust emissions reduction by application of Hydrogen engine instead of diesel in city bus

In accordance with the latter, hydrogen is good for the communities, because hydrogen buses, as example, will provide clean transportations with lower noise. But there are two sides to every coin. On the one hand, in use, hydrogen can be easily transported and storage poses no ecological problems. On the other hand, since elementary hydrogen is rare on earth, it needs to be produced. Therefore, hydrogen is considered to be secondary energy form and as such need to be produced from variety of primary sources, Figure 2 [4].

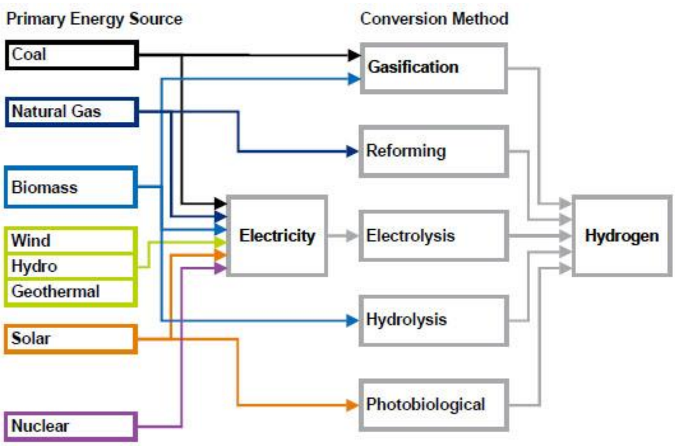


Figure 2: Some of the energy sources and processes that can be used to produce hydrogen

Two most popular means for producing of hydrogen are by steam methane reforming of natural gas as fossil source and electrolysis. It is the fact that hydrogen production capacities are limited and that in order to ensure reliable supplies for users, an infrastructure must be established first. Hydrogen can be used in vehicles, but this also requires the development of a national hydrogen refuelling infrastructure.

PROTOTYPE BUS DESIGN PROPOSITION

General Options of gaseous hydrogen storage and Propulsion system demonstrated on low floor city bus

We have started the work on prototype of fully low floor city bus with hydrogen propulsion system. The prototype bus needs to be equipped with the original internal combustion engine (ICE) designed to work only on compressed gaseous hydrogen (CGH_2). Figure 3, shows parts of the installation for CGH_2 supply from bus roof mounted gas cylinders to the engine that is proposed to prototype version of HyS bus. All parts inside of the CGH_2 installations are approved according to the regulation UN ECE TRANS/WP.29 – Global Platform for Harmonization of Legal Requirements for Road Vehicles [5,6].

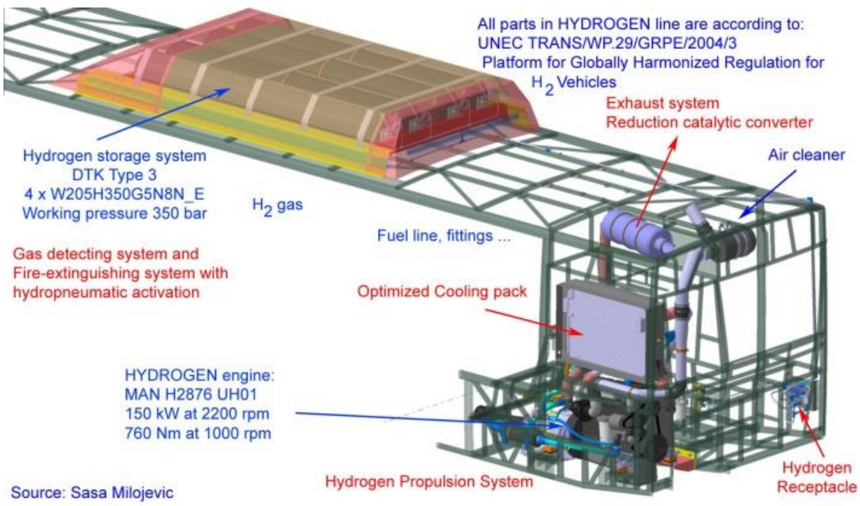


Figure 3: Sketch of the CGH_2 fuel line equipment installed on the bus

The production of a dedicated hydrogen vehicle begins with the joining of the CGH_2 cylinders with the original rack to the bus roof, Figure 3 and Figure 9. We propose CGH_2 storage system that includes type III cylinders composed of an aluminum 6061 liner reinforced by carbon fiber in epoxy resin (brand Dyne-cell®), with a favorable ratio between weight and volume (0.3 kg/L to 0.4 kg/L) [5].

During the retrofit, need to be considered existing regulations regarding to the dimensions and gross vehicle weight. Specifically, we took into account the requirements relating to the correct joining of the main parts of the CGH_2 fuel line and gas cylinders, all legislated by regulation UN ECE TRANS/WP.29 [6]. The position of the new center of gravity is depending of the added cylinders' weight with the rack on the bus roof. According to requirements for vehicles of categories M3 and N3, (resistance to destruction of the roof structure during deceleration of $6.6 \cdot g$ in the longitudinal and $5 \cdot g$ in transverse direction), we calculated and accepted the mounting of CGH_2 cylinders assembly to carry through the auxiliary steel "U" profiles, Figure 4 [2,3,6].

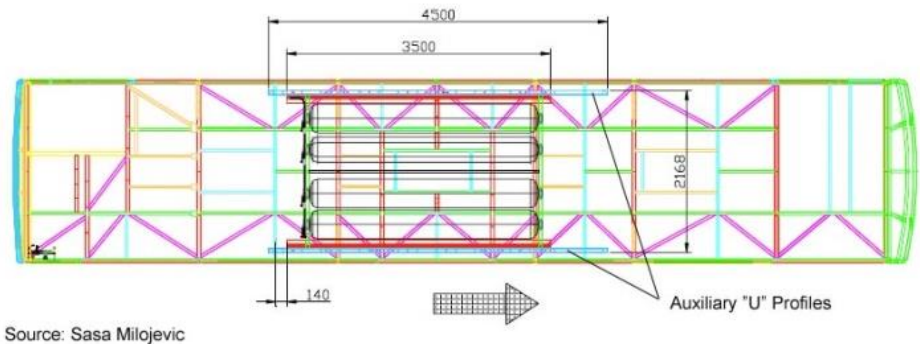
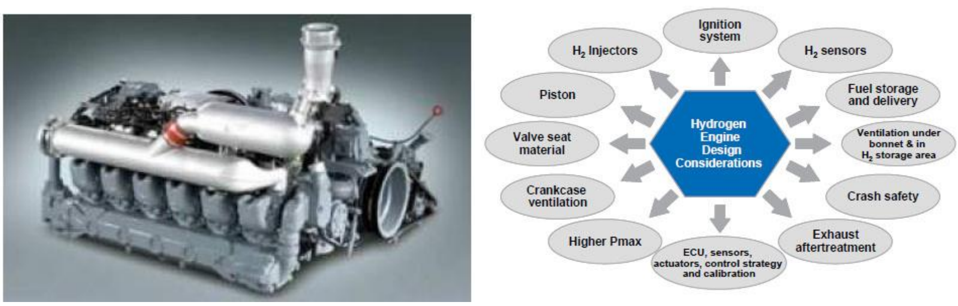


Figure 4: CGH2 Cylinders Rack position on the bus roof

HYDROGEN ENGINES – COMBUSTION CONCEPTS

Substituting conventional fuels by hydrogen in road transport can be achieved by introducing to the market new vehicles equipped with hydrogen engines, or as a first step, by converting engines of existing vehicles to run on hydrogen as an additive. The design and operation of hydrogen engine is typically based on CNG engine, requiring an ignition system inside off the spark ignite the fuel mixture. Figure 5 shows the picture of original hydrogen engine maker MAN with associated equipment specified bellows [1,4].



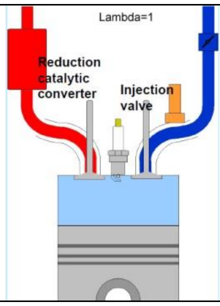
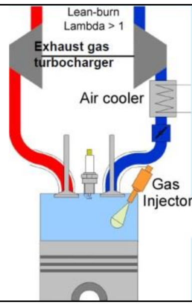
(a) *(b)*

Figure 5: Hydrogen propulsion system (a) Engine maker MAN type H2876 UH01

(b) Design and Consideration

The exhaust emission of the hydrogen engine maker MAN type H2876 UH01 achieved according to ESC emission test is presented on the Figure 1. This is naturally aspirated engine with stoichiometric combustion and external mixture formation, Table 1 [1,4].

Table 1: *Difference between combustion concepts applied inside of MAN´s hydrogen engine*

ENGINE	MAN H2876 UH01	MAN H2876 LUH01
Combustion system		
Power	150 kW @ 2200 rpm	200 kW @ 2000 rpm
Torque	760 N·m @ 1000 rpm	1000 N·m @ 1200 rpm
Concept features	✓ Lambda=1 naturally aspirated stoichiometric engine ✓ External mixture formation ✓ Spark ignition system ✓ Power regulation /throttle valve ✓ Reduction catalytic converter ✓ Conventional low cost technology …	✓ Lambda>1 lean-burn engine turbo-charging with air cooling ✓ Internal mixture formation ✓ Injection pressure (< 1 MPa) ✓ Early start of injection ✓ Spark ignition system ✓ Power regulation /throttle valve and variable air/fuel ratio ✓ No exhaust after-treatment ✓ No backfiring

According to above specified characteristics of the hydrogen engines and combustion concepts, inside of Table 2, presented are the control measures needed to be integrated inside of new improved engines.

Table 2: *Hydrogen engine control measures*

Challenges - Problems	› Control Measures
• Auto ignition in the combustion chamber • Limits rich lambda range and therefore limits torque output	• Improved combustion chamber cooling (exhaust valves) • Low hydrogen injection temperature
• Auto ignition in the inlet manifold - backfire	• Direct injection with lower risk of backfire • Careful control of inlet and exhaust valves limits the risk of backfire
• NOx is the main emission from hydrogen ICEs • NOx formation is dependent on combustion temperature	• Lean mixture, exhaust recirculation (EGR) • Lower hydrogen injection temperature • Optimize cooling strategies • Optimize injection timing • NOx after treatment system
• Port injection natural aspiration hydrogen ICEs produce less power and torque then gasoline ICEs	• Boosting • Direct injection • Stoichiometric operation

HYDROGEN USE AS AN ADDITIVE

One of options for existing buses can be the use of hydrogen as an additive where are possible two main options:

- ✓ Hydrogen can be added to the intake air of a diesel engine, with the aim of improving the combustion process characteristics, and
- ✓ Hydrogen can be injected into the exhaust system to increase temperature for regeneration of the diesel particulate filter or trap inside of after treatment system.

INSTRUCTION FOR BUSES SAFETY PROJECTING AND SERVICING

Before discussing the design features that are recommended for hydrogen buses and their propulsion system, it is important to understand what makes this fuel different from natural gas, gasoline or diesel. The items below summarize the basic differences between of their properties [4]:

- ✓ Hydrogen CGH_2 fuel systems store fuel at approx... 35 MPa, up to 70 MPa.
- ✓ Unlike gasoline vapors, natural gas and hydrogen are both lighter than air and in gaseous form at atmospheric conditions. This property allows these fuels to quickly rise and disperse in the unlikely event of a leak. Although lighter than air fuels have safety demands, roofs of service facilities must be designed without any unventilated "pockets" in the ceiling space that could trap gas. Liquid fuels such as gasoline and diesel will form a pool of liquid with a vapor layer above. Liquid fuels remain in a concentrated form after a leak, causing on-going safety and environmental concerns.
- ✓ CNG and Hydrogen (H_2) both have an ignition temperature of around 480 to 650 degrees Celsius (°C) - whereas Gasoline is approximately 260 °C to 430 °C and diesel is less than 260 °C. This relatively high ignition temperature for CNG and (H_2) is an additional safety feature of these fuels. To ensure a safe environment in the service facilities, the surface temperature of equipment that could contact a gas leak is usually limited to 400 °C.

According to previous descriptions, ventilation systems in the services for hydrogen fuelled buses must be designed to provide between 5 and 6 Air Changes per Hour (ACH) (the requirement is for 425 L/min per $1 \cdot m^2$ of ventilated area). The conclusion is that this is no additional airflow requirement and cost, according to existing diesel facilities designed for a baseline ventilation rate of 4 to 6 ACH.

In developing the bus safety concept, the fundamentally conceivable damage events were assumed. This is structured as follows:

- ✓ Prevention of an explosive atmosphere in the buses engines compartment.
- ✓ Continuous monitoring of the air and a powerful ventilation system inside of service facilities.
- ✓ Prevention due to the explosion-protected design of electrical devices …

According to previous, the selected CGH_2 cylinders for working pressure of 35 MPa or 70 MPa used for bus prototype are equipped with automatic valve type BV-350, Figure 6, or BV-700 [5]. Automatic cylinders’ valves are equipped with Pressure Relief Devices (PRD), with ultra-fast activation and high flow. Cylinders are also equipped with electric shut-off valves with unique stop fill function to stop and open the CGH_2 flow in fuel line. In the valve is integrated temperature sensor with thermal switch that quickly respond to increasing temperatures more than 110 ^{0}C as fire protection. That is so called Temperature triggered Pressure Relief Device (TPRD).

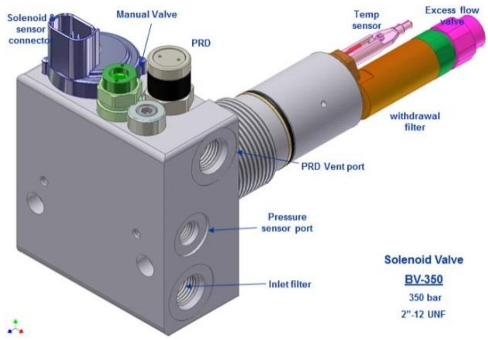


Figure 6: Automatic cylinders' valve type BV-350

HYDROGEN ON-BOARD STORAGE

At the present time, on board a vehicle Hydrogen can be stored as a compressed gas, cryogenic liquid or in a metal hydride. To make clearer the energy differences, the Table 3 shows a comparison between various forms of hydrogen and diesel fuel [1,4].

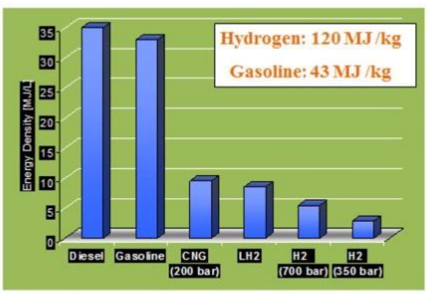
***Table 3:** Comparison of hydrogen and diesel fuel energy densities*

The energy content of:	› is equivalent to:
$1{\cdot}Nm^3$ of gaseous hydrogen	0.30 liters of diesel fuel
1 liter of liquid hydrogen	0.24 liters of diesel fuel
1 kg of hydrogen as metal hydride	2.79 kg of diesel fuel

Storage and bulk transport of hydrogen in compressed form allows satisfactory gravimetric density to be achieved, with composite cylinders. Compressed gas at maximal 35 and 70 MPa is the most likely form of hydrogen storage to be used for large vehicles such as buses and heavy duty vehicles (HDVs).

Storage in liquid form (LH_2) at about (-253 ^{0}C) and pressure of 1·MPa, allows useful volumetric and gravimetric densities to be achieved, similar to CNG, Figure 7 [1,4]. However this requires cylinders with extensive thermal insulation, to minimize evaporation. Hydrogen's low boiling point makes liquefaction very energy intensive.

Storage of hydrogen on substrates, in absorbed form, particular on metal hydrides, exhibits very attractive volumetric density, but very low gravimetric density.



Basics: 500 km mileage range		Diesel	LH_2	CGH_2
Weight in kg	Fuel	25	5	5
	Tank System	30	80	120
Volume in L	Fuel	30	74	124
	Tank System	36	150	210
Storage density in kWh/ kg	Tank System	35	3,1	1,4
Storage density in kWh/ L	Tank System	30	1,1	0,8

Figure 7: Hydrogen Energy Density vs other Fuels

ON-BOARD STORAGE OF HYDROGEN UNDER PRESSURE IN GASEOUS STATE

The available gas cylinders for on-board storage of hydrogen are classified into four categories. Type I cylinders are steel liner, while type II cylinders are steel liner wrapped with filament windings (usually glass fiber) around the cylindrical part, Figure 8. Type III cylinders are made of composite materials (initially fiberglass, and increasingly carbon fiber), with a metal liner (i.e. the inside facing, acting as H_2 barrier) – initially aluminum, lately in steel. Type IV cylinders are composite (mainly carbon fiber) with a polymer liner (mostly thermoplastic polymers, of the polyethylene or polyamide type), Figure 8 [5].

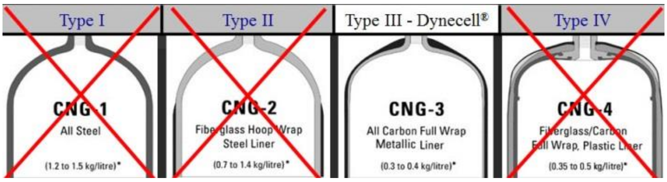


Figure 8: Comparative analysis of the (mass/volume) ratio of various cylinder types (example CNG cylinders)

In our case, on the bus roof need to be mount Gas Rack with minimum seven CGH_2 cylinders, as example type "W205H", with a total water capacity of 1435 L, Figure 9. The weight of one cylinder was about 92.4 kg (0.308 kg /L). The selected composite cylinders are lightweight cylinders for the storage of CNG and CGH_2. They consist of a thin-walled, seamless aluminum internal vessel whose entire surface is wrapped with a high-strength carbon fiber reinforcement (Type III = "fully wrapped metal liner") [2,3,5]. On the Figure 4, presented is CGH_2 Cylinders Rack position on the bus roof.

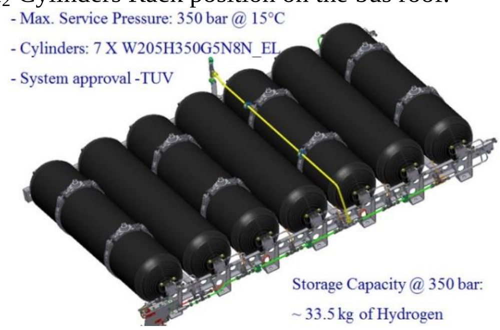


Figure 9: CGH2 cylinders rack W205H for bus application

HYDROGEN MARKET SUPPLY AND CGH_2 BUSES FILLING

The source-to-tank CO_2 emissions for hydrogen depend on the primary energy sources and productions method. Hydrogen can be produced from a number of CO_2 neutral sources, such as renewable electricity, biomass, nuclear power, Figure 2. Hydrogen from a central production plant could be delivered to the filling stations via pipeline, Figure 10. In Europe, however, only 1,000 km of hydrogen pipelines exist. The security of the CGH_2 supply is required to continue the introductions of hydrogen vehicles in city transport [4].

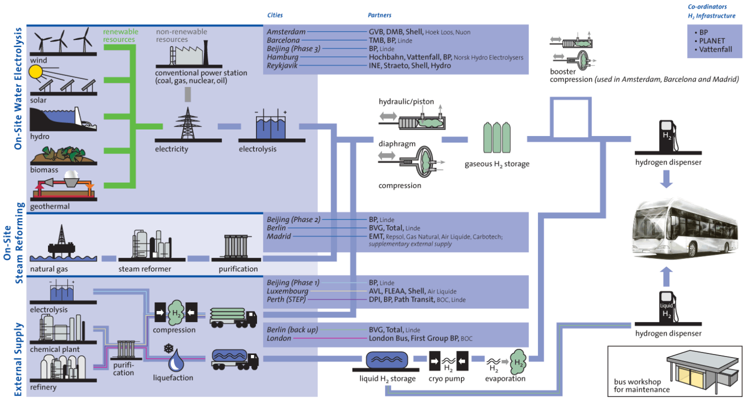


Figure 10: *Hydrogen Supply Options in Cities*

As second option, a truck for supply of LH_2 can carry up to about 3.3 tons of LH_2, equivalent to about 36,700 Nm^3. A drawback of liquid supply is that, due to the very low temperatures, all storage vessels have to be very well insulated. Small amounts of hydrogen can also be lost if the station is not being used for refueling for prolonged periods as hydrogen can start to boil and has to be vented in order to stay below the maximum pressure of the vessel. Another disadvantage is the high energy demand for liquefying hydrogen. It amounts to about one third of the energy contained within the LH_2 ($1 \cdot Nm^3$, containing 3.54 kW·h, requires more than 1·kW·h). Given the comparably short distances from central production sites to hydrogen customers, gaseous delivery is dominant in Europe [4,5].

Third options, bulk transport where is CGH_2 stored under pressure of 200 bar, while maximum pressure currently being 300 bar. A trailer can deliver between 300 and 600 kg of CGH_2. Delivery will thus only last for a very limited span of time. Unless two trailers are parked on site, the schedule for exchanging them will be tight and has to work on a strict just in- time basis to guarantee fuel supply for the buses, Figure 11 [5].

(a) *(b)*

Figure 11: The 300 bar Modules (a) ISO 20 ft Container (b) 10 ft Cube for Bulk Transport of CGH_2

CONCLUSIONS

(1) Use of Compressed Gaseous Hydrogen as an alternative fuel is an effective, currently available way to help solve environmental and fuel resource problems. Generally, hydrogen has safety advantages compared to gasoline and diesel: it is non-toxic, neither carcinogenic nor corrosive gas.

(2) The introduction or expansion of hydrogen vehicles will require investment in new refueling infrastructure.

(3) When deciding to introduce or expand the use of hydrogen buses, one must evaluate the appropriate hydrogen engine technology. Lean-burn heavy-duty hydrogen engines were popular due to their lower engine-out NOx emissions and higher fuel efficiency compared to stoichiometric engines. To meet the most stringent Euro VI emission standard for NOx, it is necessary to switch to stoichiometric combustion combined with exhaust gas recirculation and three-way catalyst after-treatment.
(4) By installing the Gas Rack with Cylinders for gaseous hydrogen storage of Type III and rest fuel equipment homologated according to the UN ECE TRANS/WP.29, it was achieved progress from the aspect of vehicle safety in traffic.

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REFERENCES

[1] Knorr, H., Held, W., Prumm, W. and Rudiger,H. (1998). The MAN hydrogen propulsion system for city buses. *Int. J. Hydrogen Energy*, 23, 3, 201-208.

[2] *Journal: Intellectual Property Gazette*. Milojević, Saša, Ilić, Nenad and Vujović, Zoran. 2012. Mounting the compressed natural gas storage tanks on the top of the bus roof with the steel roof racks. The Intellectual Property Office of the Republic of Serbia, Belgrade, 2012/2, pp.725.

[3] Milojevic, S. and Pesic, R. (2012). Theoretical and experimental analysis of a CNG cylinder rack connection to a bus roof. *Int. J. Automotive Technology*, 13, 3, 497-503. DOI 10.1007/s12239−012−0047−y. eISSN 1976-3832.

[4] *Scientific and Technical Objectives of the HYFLEET: CUTE Project*.

[5] Website: http://www.global-hydrogen-bus-platform.com/Technology/ScientificandTechnicalObjectives.

[6] Accessed on May 15, 2014.

[7] Rasche, C.: "Advanced Lightweight Fuel Storage Systems TM", *Dynetek Europe GmbH Presentation*.

[8] *Website:* http://www.dynetek.com/pdf/AGMPresentation2009.pdf. Accessed on August 18, 2013.

[9] United Nations, 2003, *Proposal for a new draft regulation: Uniform provisions concerning the approval of: 1. Specific Components of Motor Vehicles Using Compressed Gaseous Hydrogen; 2. Vehicles with Regard to the Installation of Specific Components for the Use of Compressed Gaseous Hydrogen*, UN ECE Regulation: TRANS/WP.29/GRPE/2004/3, United Nations, New York.

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