

Examination of selected electric vehicles in respect of optional safety

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Abstract. Environmental protection considerations as well as the predicted running out of global crude oil resources force the manufacturers of vehicles with internal combustion (IC) engines to search for alternative propulsion sources. In difficult road conditions, vehicle occupants are exposed to various hazards, especially to health and life. This forced the Automotive Industry Institute (PIMOT) to attack the important problem named “Electric Vehicles’ Operational Safety (EVOS)”. In the paper published previously at Conference KONMOT 2016, the authors presented an EVOS examination and assessment concept.

The paper presents results of comparative tests and EVOS assessment carried out for four electric vehicles of various sizes: OPEL Ampera, RENAULT ZOE, MITSUBISHI MiEV and SAM EV. The presented results of testing the sample EVs show how much the vehicles differ from each other and how much work still has to be done for improvement of the safety of their operation. Based on the work results, detailed EVOS assessment criteria may be prepared. The criteria prepared and test results obtained may be utilized in research works on electric vehicles, in the production of such vehicles and their components, and in the selection of vehicles, especially by transport companies.

1. Introduction

1.1. EVOS 1 assessment

The EVOS 1 assessment is based on results of tests for conformity with the requirements described herein. The assessment results are obtained by calculating the “overall EVOS assessment index” from the weighted average calculation formula as given below. For the four quantities adopted as indicators (W_1 , W_2 , W_3 , and W_4), this formula takes the form:

$$W_{B1} = \frac{W_1 * u_1 + W_2 * u_2 + W_3 * u_3 + W_4 * u_4}{u_1 + u_2 + u_3 + u_4} \quad (1)$$

where: W_{B1} – overall EVOS 1 assessment index;
 W_1 – score given in the assessment of mechanical vibrations;
 W_2 – score given in the assessment of internal noise;
 W_3 – score given in the EMC assessment;
 W_4 – score given in the assessment of electrical safety;
 u_1, u_2, u_3, u_4 – weights of individual scores in the overall index.

In result of an analysis carried out, the following weights were adopted, with $\sum u = 1$:

$$u_1 = 0.25 \quad u_2 = 0.20 \quad u_3 = 0.25 \quad u_4 = 0.30 \quad (2)$$

1.2. EVOS 2 assessment

For the EVOS 2 assessment, results of the tests and assessment of the electric vehicle to the EVOS 1 procedure are utilized. The scope of this assessment is widened by additionally taking into account the Vehicle Safety Systems (VSS) provided. The overall EVOS 2 assessment index is determined from the following formula:

$$W_{B2} = W_{B1} * (B_x + 1) \quad (3)$$

where B_x is the safety systems factor for the vehicle under assessment.

B_x is calculated from the following equation, for the numbers of the systems and separate technical units that are dedicated to vehicle safety, adopted in accordance with Table 1:

$$B_x = \frac{\sum_{i=1}^{i=l} s_i}{l_p} \quad (4)$$

where: $\sum_{i=1}^{i=10} s_i$ – actual total score;
 l_p – maximum possible total score.

Table 1. Scores proposed for the safety equipment of an electric vehicle

Equipment symbol	Description of the system or separate technical unit	Manufacturer's symbol	Score [points]
S1	Seat belts with pretensioners	SRS	0-10
S2	Airbags	Various	0-10
S3	Braking systems with antilock and anti-slip systems, brake assist systems, etc.	ABS, ASR, EBD, EBS, etc.	0-10
S4	Vehicle travel path stabilization system, e.g. electronic stability program	ESP	0-10
S5	Active cruise control system	ACC	0-10
S6	Obstacle detection system and system of automatic braking	Various	0-10
S7	Warning systems, monitoring driver fatigue or lane departure	Various	0-10
S8	Lighting and visibility improving systems	Various	0-10
S9	Monitoring of road incidents	e-Call	0-10
S10	Others		0-10
Total, maximum			100

The scores given for individual parameters of the vehicles under test has basically been adopted according to items 1-6 of the Table above as proposed by the authors in publication [14] cited previously. In consideration of technological progress, the requirements for internal noise have been tightened by 2 dB. At present, the following scores are given according to results of the assessment of internal noise:

74 dB(A)	1 point
72 dB(A)	2 points

70 dB(A)	3 points
68 dB(A)	4 points
66 dB(A)	5 points
64 dB(A)	6 points

It is suggested that the scores proposed in publication [14] should be adopted for the assessment of plug-in hybrid electric vehicles (PHEV).

2. Technical specifications of the vehicles under test

Four mass-produced electric vehicles were subjected to the EVOS tests within this work:

- OPEL Ampera;
- RENAULT ZOE;
- MITSUBISHI i-MiEV;
- SAM EV.

Technical specifications of these vehicles have been given in Table 2.

Table 2. Technical specifications of the vehicles under test

Parameter	OPEL Ampera	RENAULT ZOE	MITSUBISHI i-MiEV	SAM EV
Body type	sedan	hatchback	hatchback	two-seater
– doors	5	5	5	2
– seats	4	4	4	2
Curb mass [kg]	1 715	1 470	1 110	750
Gross vehicle mass [kg]	2 080	1 965	1 450	1 055
Luggage capacity [dm ³]	300	335	256	Not available
Electric motor	AC	AC	AC	AC
– power output, continuous [kW]	111	68	49	14.7
– rated voltage [V]	950	400	330	110
Traction battery				
– capacity [kWh]	16	22 / 41	16	about 10
– type	lithium-ion	lithium-ion	lithium-ion	lithium-ion
Maximum speed [km/h]	161	135	130	85
Acceleration 0-100 km/h [s]	9	13,2	15,9	Not available
Range [km]	56 ^x	240 / 400	150	about 100
Body dimensions:				
– length [cm]	441	409	348	307
– width [cm]	180	173	148	158
– height [cm]	143	156	161	159

^x - with additional drive (HEV) approx. 500 km

All the tests of the vehicles under consideration were carried out in compliance with the requirements specified in publication [14].

3. Test results

In result of an identification of vehicles Nos 1, 2, 3, and 4, the data provided in the vehicle documents (vehicle registration certificates) were found to be in conformity with the actual vehicle identification data marked on the vehicles.

3.1. Mechanical vibration tests

The test results have been presented in Table 3.

Table 3. Results of measurements of mechanical vibrations of the vehicles under test

Vehicle No.	RMS acceleration values [m/s^2]	Score [points]
1	0.43	5
2	0.69	4
3	0.75	4
4	1.10	3

3.2. Internal noise tests

The test results have been presented in Table 4.

Table 4. Results of measurements of internal noise in the vehicles under test

Vehicle No.	Acoustic pressure values [dB(A)]	Score [points]
1	66.9	4
2	65.8	5
3	67.3	4
4	69.7	3

3.3. EMC tests

The tests were carried out within the scope of broadband electromagnetic emissions in two frequency ranges: 30-300 MHz and 300-1 000 MHz, with the use of two antenna systems. The test results have been given in Table 5. Example curves illustrating the broadband emissions measured for the OPEL Ampera vehicle have been shown in the graphs in Figs 1 and 2.

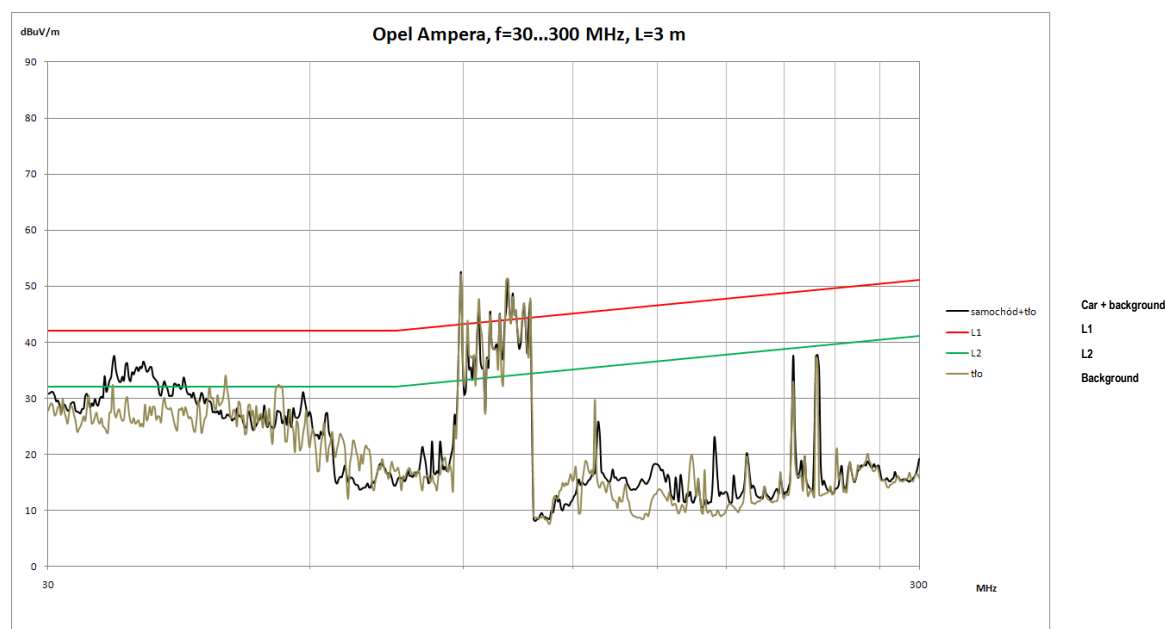


Figure 1. Example curve illustrating the broadband electromagnetic emissions measured for the OPEL Ampera vehicle; $f = 30\text{--}300\text{ MHz}$; L1 – normative requirements; L2 – requirements tightened by 10 dB in relation to L1 (see [14])

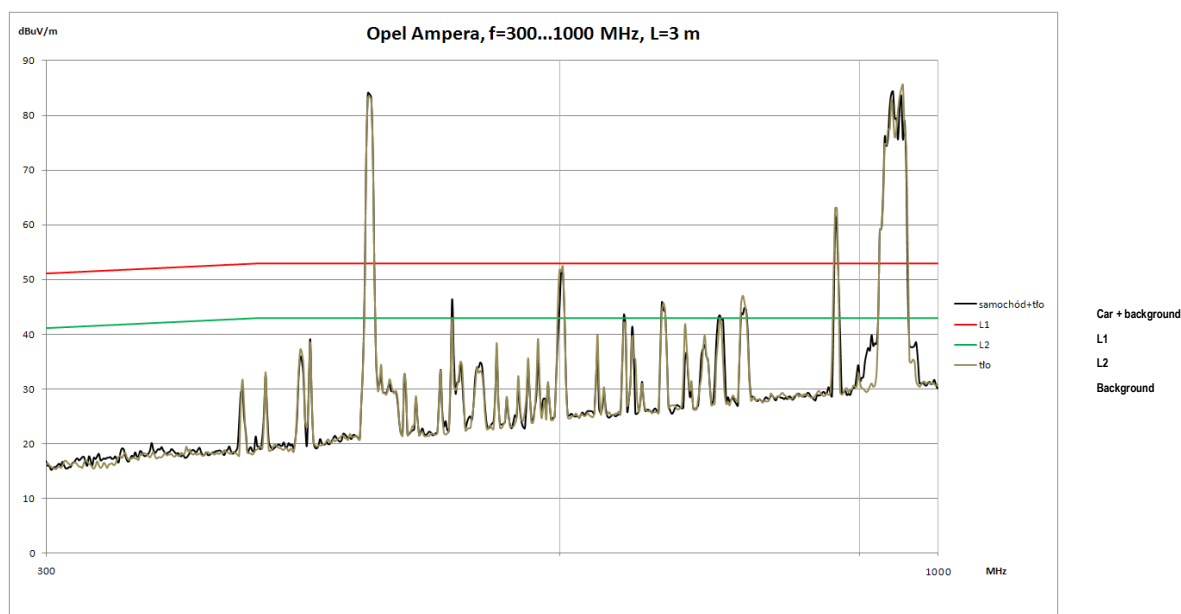


Figure 2. Example curve illustrating the broadband electromagnetic emissions measured for the OPEL Ampera vehicle; $f = 300\text{--}1\,000\text{ MHz}$; L1 – normative requirements; L2 – requirements tightened by 10 dB in relation to L1 (see [14])

Table 5. Results of testing the EMC of the vehicles under test (broadband emissions)

Vehicle No	Score [points]
1	4.5
2	4.0
3	3.5
4	3.0

3.4. Electrical safety tests

The test results have been presented in Table 6.

Table 6. Results of checking the electrical safety within the scope of the IP Code system of equipment protection classes and the working voltage of the equipment

Vehicle No.	IP Code	IP score [points]	Working voltage [V]	Voltage score [points]	Overall score [points]
1	54	4	950	0	2.0
2	44	3	400	2	2.5
3	44	3	330	2	2.5
4	42	2	110	4	3.0

In the preliminary tests, the insulation resistance was not tested; instead, an assumption was made that the minimum acceptability level of $500\ \Omega/\text{V}$, as required by UN ECE Regulation No 100, was met.

3.5. Tests to determine the safety systems factor B_x

Results of the tests and calculations based on Table 1 and equation (4), carried out to determine the safety systems factor B_x , have been presented in Table 7.

Table 7. Results of determining the safety systems factor B_x of the electric vehicles under test

Vehicle No.	Symbols of vehicle equipment and separate technical units										$\sum S$ [points]	B_x [points]
	$S1$	$S2$	$S3$	$S4$	$S5$	$S6$	$S7$	$S8$	$S9$	$S10$		
1	8	8	8	5	0	0	0	5	0	5	39	0.39
2	8	8	6	5	0	0	0	5	0	0	33	0.33
3	5	4	2	0	0	0	0	5	0	0	16	0.16
4	2	2	0	0	0	0	0	2	0	0	6	0.06

4. Analysis of the test results

The comparative examinations carried out to assess the vehicles under consideration and their safety systems enabled practical verification of the EVOS assessment method prepared in the form as proposed in the concept presented in [14].

- 1°. Results of the EVOS 1 calculations based on formula (1), carried out for the vehicles under test, have been given in Table 8.

Table 8. Results of the EVOS 1 assessment of the vehicles under test

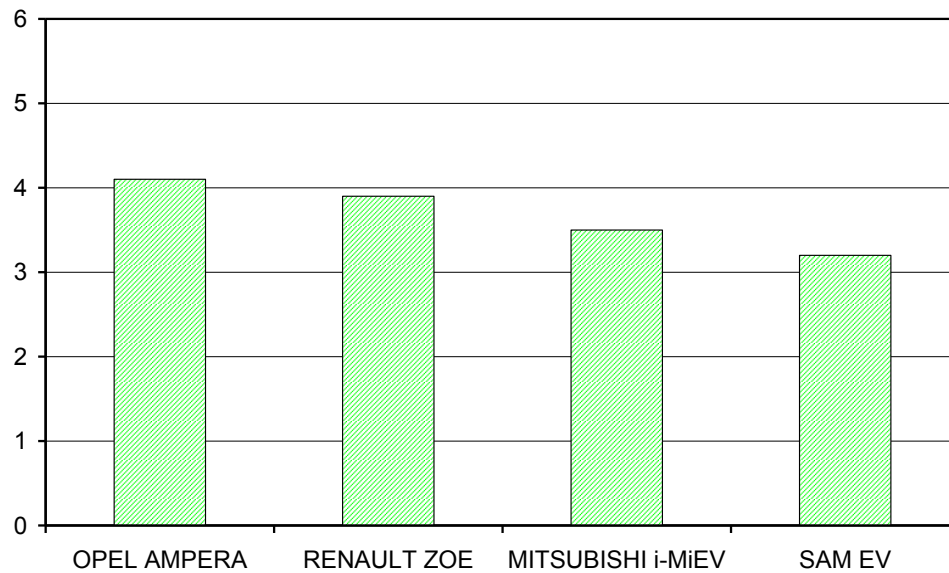
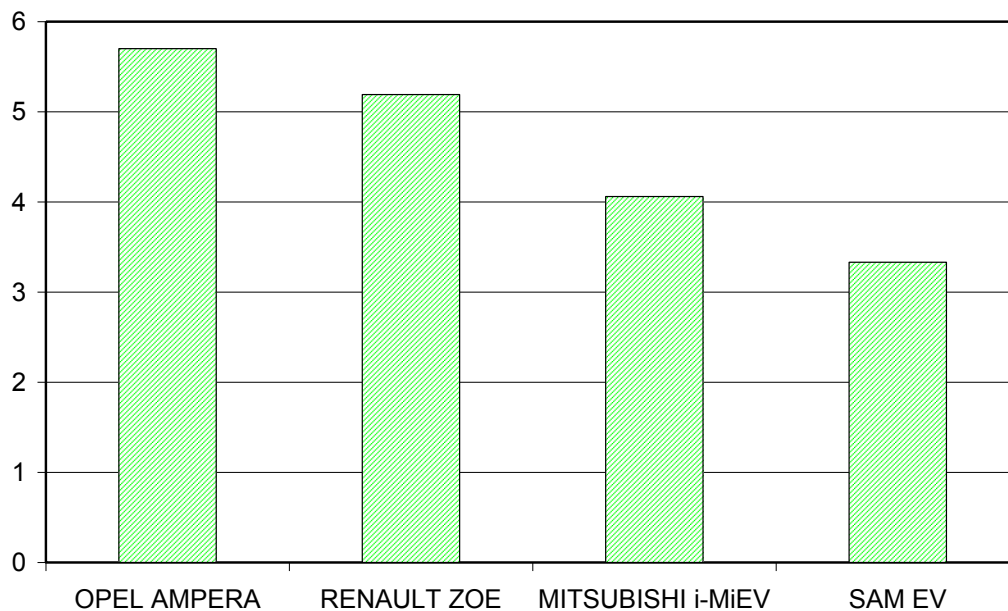
Vehicle No.	Make and model	Score [points]				EVOS 1 W_{B1}
		W_1	W_2	W_3	W_4	
1	OPEL Ampera	5	4	4.5	2.0	3.9
2	RENAULT ZOE	4	5	4.0	2.5	3.8
3	MITSUBISHI i-MiEV	4	4	3.5	2.5	3.5
4	SAM EV	3	3	3.0	3.0	2.9

- 2°. Results of the EVOS 2 calculations based on formula (3) and the B_x factor values determined have been given in Table 9.

Table 9. Results of the EVOS 2 assessment of the vehicles under test

Vehicle No.	Make and model	W_{B1}	B_x factor	EVOS 2
		(EVOS 1 assessment)		W_{B2}
1	OPEL Ampera	3.9	0.39	5.42
2	RENAULT ZOE	3.8	0.33	5.05
3	MITSUBISHI i-MiEV	3.5	0.16	4.06
4	SAM EV	2.9	0.06	3.07

The EVOS 1 and EVOS 2 calculation results in graphical form for the four vehicles under test have been presented in Figs. 3 and 4.

EVOS 1 assessment**Figure 3.** W_{B1} calculation results**EVOS 2 assessment****Figure 4.** W_{B2} calculation results

The average W_{B1} value was 3.67 points, as against a maximum of 6 points.

The average W_{B2} value was 4.57 points, as against a maximum of 12 points.

The relatively low value of the W_{B2} index shows, *inter alia*, that electric vehicles are rather poorly equipped with safety systems as against the standards adopted by leading motor vehicle manufacturers.

3°. In result of the EVOS 2 examinations carried out, the electric vehicles under consideration may be granted the EVOS classes as specified below, according to Table 8 in Section 3 of publication [14].

Table 10. The EVOS classes granted to the vehicles under test

Vehicle No.	Make and model	EVOS class
1	OPEL Ampera	C
2	RENAULT ZOE	C
3	MITSUBISHI i-MiEV	D
4	SAM EV	–

5. Recapitulation

The objective of this work was to verify, by practical testing, the concept of a method to assess the Electric Vehicles' Operational Safety (EVOS) as proposed in publication [14].

The essence of the research task was to verify the EVOS assessment criteria, especially in respect of mechanical vibrations, internal noise, electromagnetic radiation, protection against electric shock, and additional factors, on specific models of electric cars.

This paper shows results of tests carried out on four different vehicles, i.e. OPEL Ampera, RENAULT ZOE, MITSUBISHI i-MiEV, and SAM EV, based on the following three-level EVOS assessment method:

- EVOS 1 assessment (carried out in respect of the criteria described in subsections 2.1 to 2.5 of publication [14]).
- EVOS 2 assessment (an expanded version of the EVOS 1, where criteria concerning the safety equipment of the vehicle are added).
- Granting of EVOS classes: there are 5 different classes, which may be granted to a specific EV type and individual packages of its optional equipment, based on the EVOS 2 assessment.

At the EVOS 2 assessment, a “safety systems factor” has been introduced to take into account the current technological progress in this field and the safety equipment provided in the electric vehicles under consideration.

The results of testing the sample electric vehicles show how much the vehicles differ from each other and how much work still has to be done for improvement of the safety of their operation. Two of the four vehicles under test were granted class C, another one obtained class D, and one did not qualify for any EVOS class.

In result of the analysis, it has been suggested that the range of applicability of the EVOS assessment method should be extended to plug-in hybrid electric vehicles (PHEV). With this objective in view, the requirements concerning internal noise have been modified. Within the further works, it would be reasonable to develop an EVOS assessment procedure for other vehicles with hybrid drive systems, which have already become a considerable segment of the market.

The criteria prepared may be utilized in research works on electric vehicles, in the production of such vehicles and their components, and in the selection of vehicles, especially by transport companies. The implementation of the EVOS criteria having been prepared should help to improve the road traffic safety by reducing the hazards revealed during the research work.

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