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MOBILITY & VEHICLE MECHANICS

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IMPROVEMENT OF ENERGY EFFICIENCY OF CITY VEHICLE FLEETS: CASE STUDY

Davor Končalović [1], Dubravka Živković [2], Dušan Gordić [3], Vladimir Vukašinović [4], Mladen Josijević [5], Slađana Stević [6]*

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RESEARCH ARTICLE

ABSTRACT: The subject of this paper are measures for improvement of the energy efficiency of fleets that are in the jurisdiction of the one city in Serbia. Improvement of energy efficiency is proposed thorough following five measures: Data collection, internal benchmarking, transparency, the publication of collected information and rewarding of good practice examples; Creation of a joint fleet, joint driving and driving pairing (car sharing in public institutions); Establishment of eco-driving programs in the City Administration; Tire pressure control and The transition of a part of the petrol fleet to liquid petroleum gas. Here proposed methodology is easily understandable, characterized by transparency and easy adaptation while monitoring the results of the implementation of proposed measures is intuitive and simple.

KEY WORDS: fleet management, energy efficiency, energy management system

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[1]*Davor Končalović, PhD, assist. prof., University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, davor.koncalovic@kg.ac.rs (*Corresponding author)*
[2]*Dubravka Živković, PhD, research assist., University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, dubravka@kg.ac.rs*
[3]*Dušan Gordić, PhD, full prof., University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, gordic@kg.ac.rs*
[4]*Vladimir Vukašinović, PhD, assist. prof., University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, vladimir.vukasinovic@kg.ac.rs*
[5]*Mladen Josijević, Teaching assist., University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia, mladen.josijevic@fink.rs*
[6]*Slađana Stević, City Administration for Project Management, Sustainable and Balanced Development, 34000 Kragujevac, Serbia, sstevic@kg.org.rs*

The total investment is estimated on less than 100.000 €, while savings are almost double that value in the first year of implementation of measures, suggesting a large space for energy management measures and that fleets are relatively poorly managed up to date.

POBOLJŠANJE ENERGETSKE EFIKASNOSTI VOZNOG PARKA GRADSKIH VOZILA: STUDIJA SLUČAJA

REZIME: Predmet ovog rada su mere za poboljšanje energetske efikasnosti voznih parkova koje su u nadležnosti jednog grada u Srbiji. Poboljšanje energetske efikasnosti predlaže se kroz implementaciju pet mera: Prikupljanje podataka, interno vrednovanje, transparentnost, objavljivanje prikupljenih informacija i nagrađivanje primera dobre prakse; Formiranje zajedničkog voznog parka, uspostavljanje zajedničke vožnje i uparivanja automobila (deljenje automobila u javnim institucijama); Uspostavljanje programa ekološke vožnje u Gradskoj upravi; Kontrola pritiska u gumama i Prelaz dela benzinske flote na tečni naftni gas. Ovde predložena metodologija je lako razumljiva, karakteriše je transparentnost i lako prilagođavanje, a praćenje rezultata primene predloženih mera je intuitivno i jednostavno. Ukupna investicija procenjena je na manje od 100.000 €, dok su očekivane uštede dvostruko veće već u prvoj godini primene mera, što ukazuje na veliki prostor za mere upravljanja energijom kao i da se voznim parkovima do sada relativno loše upravljalo.

KLJUČNE REČI: upravljanje voznim parkom, energetska efikasnost, sistem upravljanja energijom

IMPROVEMENT OF ENERGY EFFICIENCY OF CITY VEHICLE FLEETS: CASE STUDY

Davor Končalović, Dubravka Živković, Dušan Gordić, Vladimir Vukašinović, Mladen Josijević, Slađana Stević

1. INTRODUCTION

The subject of this paper is to propose measures to improve the energy efficiency of the vehicle fleets under the jurisdiction of the one Serbian city administration. The administration is responsible for the management of 40 fleets of 40 public utility companies, cultural institutions, agencies, sports institutions, schools, pharmacies, centers and other local government units necessary for the day-to-day operation of city establishments.

Energy consumption by the aforementioned fleets in 2016. are 213,000 litters of gasoline, 726,000 litters of diesel fuel and 52,500 litters of liquefied petroleum gas i.e. around 1.1 million euros in total. Just to illustrate, one percent of energy savings will result in an annual savings of about €11,000.

The benefits of the approach presented here are reflected in a simplified, easy to understand, graphical representation of the savings potential.

2. OVERVIEW

The city administration of the City is (to a greater or lesser extent) responsible for the operation of fleets in a total of 40 public companies with a total of 334 vehicles in the territory of the City (from ownership of vehicles to participation in the management structure of the company/institution). These fleets vary in size between 1 and 55 vehicles, with an average fleet size of 8 vehicles. All vehicles are grouped into followings groups (Figure 1) according to [1]:

- M1 – vehicles intended for the carriage of persons having, in addition to the driver's seat, maximum eight seats (245 vehicles)
- N1 – vehicles intended for the carriage of goods and having a maximum mass not exceeding 3,5 tonnes (44 units)
- N2 and N3 – vehicles intended for the carriage of goods and having a maximum mass exceeding 3,5 tonnes but less than 12 tonnes (N2) and vehicles intended for the carriage of goods with a maximum mass exceeding 12 tonnes (N3) (total of 35 vehicles)
- T – tractors (10 units).

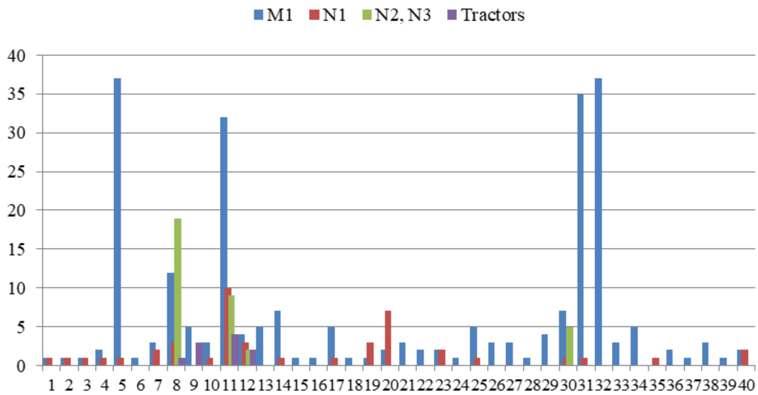

Figure 1. Structure of vehicle fleet by vehicle category

Most vehicles use gasoline (158 vehicles), then diesel (141 vehicles) while the smallest number of vehicles are driven by liquid petroleum gas (35 vehicles) (Figure 2).

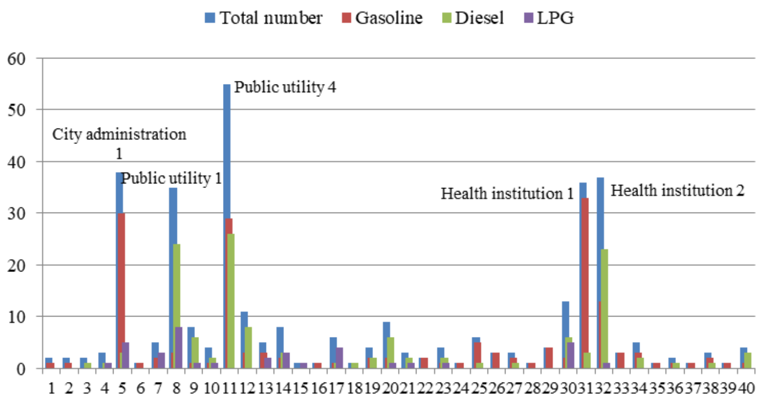

Figure 2. Structure of fleets of public companies by fuel

Vehicles average 11,500 km a year (2016), i.e. 10,000 km (2015), which is relatively small mileage given the purpose of vehicles (the European average is about 22,000 km per year for similar vehicles). Presence of the vehicles with low mileage suggests:

- High costs per kilometer caused by high fixed costs (maintenance, depreciation, registration and insurance costs)
- inadequate fleet management or inadequately sized vehicle fleet since the average vehicle mileage per day is only 38 km (for the year that has 260 working days), i.e. if they move at a speed of 50 km/h in traffic, cars are running about 45 minutes a day.

3. ANALYSIS

Figure 3 shows the fleets according to the cumulative number of kilometers traveled and the costs for fuels, while the size of the "balloon" corresponds to the size of the vehicle fleet (number of vehicles). The trendline shows that higher costs and more mileage have been driven by fleets of companies with more vehicles, and vice versa. Also, from the diagram, it can be noted that the company "Public Utility 1" deviates significantly from the trend line, which can be explained by the specific nature of the job, the fleet is dominated by trucks, moving at low speeds with frequent stops. For this reason, but also because of the fact that they recently invested in fleet renewal, "Public Utility 1" will not be the subject of specific measures but only of general measures in this paper. Similar treatment and similar reasons will also exclude two more Public Utility companies (because of the heavy-duty working regimes of vehicles) and one driving school from this analysis. Once measures are implemented and the data collection system is strengthened (and fuel consumption data per vehicle is available), these fleets will be treated like others.

Note: The potential for energy savings in the aforementioned three Public companies and Driving school is large (around 700,000 € per year, i.e. about 70% of the total energy used by 40 fleets treated here). In addition, only "Public Utility 1" consumes the same amount of fuel as the remaining 39 fleets together, i.e. "Public Utility 1" is responsible for half of the total energy consumed.

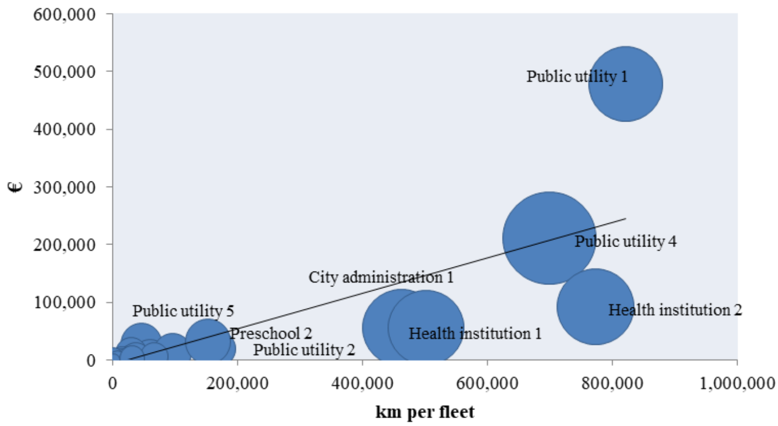

Figure 3. Vehicle fleets according to the cumulative mileage and the fuel costs, while the size of the "balloon" corresponds to the number of vehicles in a fleet

Figure 4 shows a trend line that shows the expected distribution of these sizes. The next few images will show the diagrams that follow from the diagram shown in Figure 10, followed by comments and adequate conclusions.

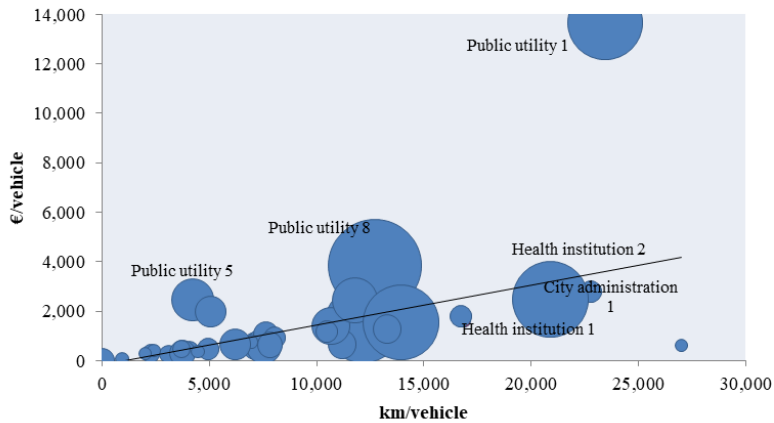

Figure 4. Vehicle fleet according to specific indicators (per vehicle)

Figure 5 shows the above-mentioned fleets, this time according to specific indicators. The picture shows the impact that exclusion of the abovementioned three Public Utilities and one Driving School have on the trend line. Clearly, that exclusion resulted in more coherent data that are describing the remaining fleets. In order to reduce the error, the fleet that is on far-right down is also removed from the analysis, since it is not possible for a vehicle to have such low operating costs, which, on the other hand, indicates the need for strengthening the data collection system.

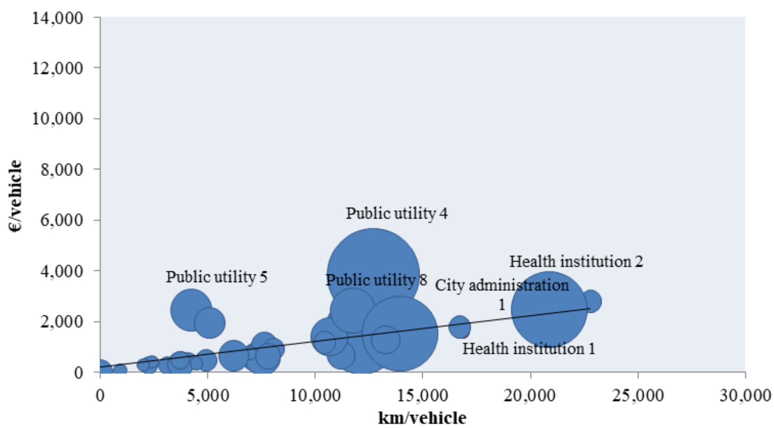

Figure 5. Car parks according to specific indicators (per vehicle) after the exclusion of three public companies

Figure 6 shows the newly emerging situation and the apparent coherence of the data. The trend line now shows a clear dependence between the number of miles traveled per vehicle and fuel costs, also per vehicle. The figure is now showing 36 fleets with a total energy consumption of around 3 GWh in 2016, or 340,000 euros.

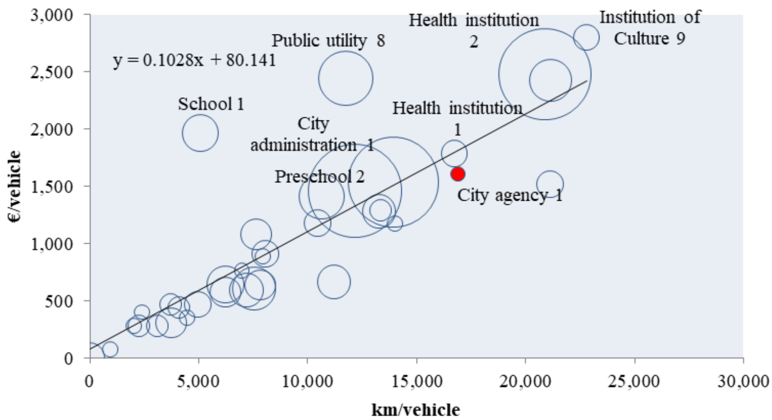

Figure 6. Fleets according to specific indicators (per vehicle) after the correction of the value on the ordinate

Figure 6 is a content identical to Figure 5 with a difference in the maximum values on apices and ordinates. This change provides a better insight into the data, i.e. it emphasizes somewhat smaller and somewhat larger (more significant) deviations from the trend line. The attention should be paid to the trend line and the red dot that presented the proclaimed referent fleet, which is now below the trend line, i.e. the consumption of energy by the vehicles of that fleet is below the average, therefore - an example of good practice. After the implementation of individual measures, this point will change the relative position relative to the trend line, which will be seen in the following Chapter.

4. RESULTS AND MEASURES PROPOSED

Improvement of energy efficiency is proposed through five measures, loosely based on [2, 3]:

- Data collection, internal benchmarking, transparency, the publication of collected information and rewarding of good practice examples
- Creation of a joint fleet, joint driving and driving pairing (car sharing in public institutions)
- Establishment of eco-driving programs in the City Administration
- Tire pressure control
- The transition of a part of the petrol fleet to liquid petroleum gas.

4.1 Measure 1: Data collection, internal benchmarking, transparency, the publication of collected information and rewarding of good practice examples

By analyzing the situation in Figure 6, it can be noticed that a group of fleets is located on the upper side of the trend line, i.e. represent a significant potential for energy savings in relation to the group of fleets that are located on the underside of the trendline. The potential savings that come from approaching the trend line of fleets that are now above the trend line is € 62,000, i.e. about 6% of the total energy consumed.

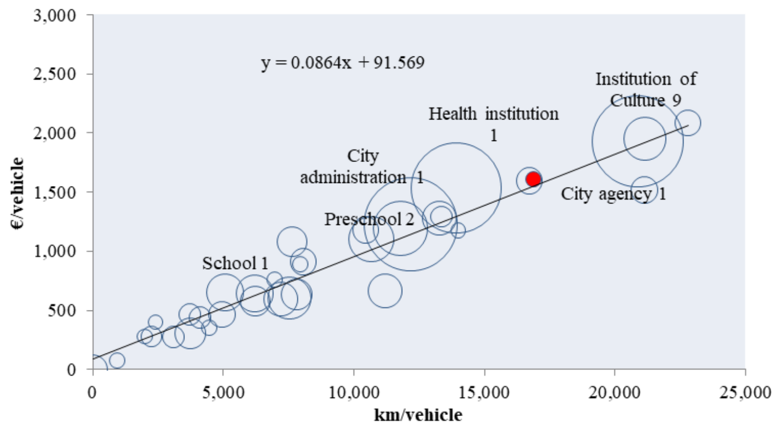

Figure 7. Enterprises after the implementation of the measure of matching the indicators resulting from internal benchmarking

The measure is implemented through:

- cooperation with the persons responsible for the fleet (fleet manager if that position exists)
- pointing to the fact that they have entered an internal benchmarking system in which their indicators are followed
- Introduction of the tracking/monitoring system to individual vehicles in order to locate potentially problematic points, ie vehicles and/or drivers
- Use of the monitoring system to locate good practice examples and awarding individual drivers
- The individual approach through provision of technical and consulting support in order to find ways to reduce fuel consumption in the fleets concerned.

After the implementation of the measure (Figure 7), it is noted that the referent fleet (red dot) is above the trendline, i.e. it isn't an example of good practice anymore, which means that (together with other fleets above the trendline) it becomes the subject of the next iteration of the same measure.

4.2 Measure 2: Creation of a joint fleet, joint driving and driving pairing (car sharing in public institutions)

This measure proposes the merging of fleets with less than 10.000 km/year/vehicle except in the case of fleets that are of interventional or emergency character. The creation of the joint fleet under the centralized management of experienced personnel in the traffic field is proposed. When analyzing data from Figure 7, it was noticed that half (20) of the total number of fleets per vehicle per year is making less than 10,000 kilometers. These fleets have a total of 61 vehicles i.e. on average 1.6 vehicles per fleet. On average, the vehicles from the mentioned group exceed 5.034 kilometers per year, or 20 kilometers per day or, at a speed of 25 km/h, only about 40 minutes per day in traffic.

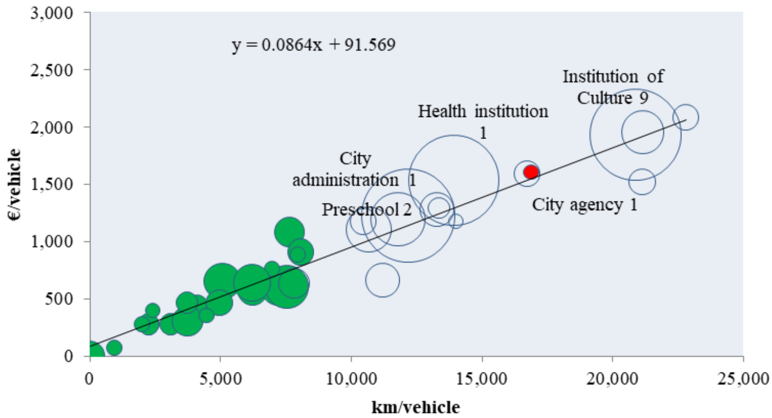

Figure 8. Car parks of public companies that exceed less than 10,000 km/year per vehicle

Mentioned fleets are characterized by a high cost of exploitation, ie, high cost per mileage. This cost is the result of fixed costs (registration, insurance, part of maintenance costs, depreciation costs). It is estimated that in the presented circumstances, the price of the crossed kilometer is 0.35 € if the cost of depreciation is assumed to be 100,000 dinars per year per car. These costs per kilometer are very close to the price of taxi services in the city, which is 0.41 € per kilometer. The proposed establishment of a city fleet aims at the reduction of these fixed costs. The assumption is that the existing 61 vehicles can be replaced with up to 20 vehicles. The situation after the implementation of the measure is shown in **Error! Reference source not found.** (shaded fleet is hypothetical newly established fleet).

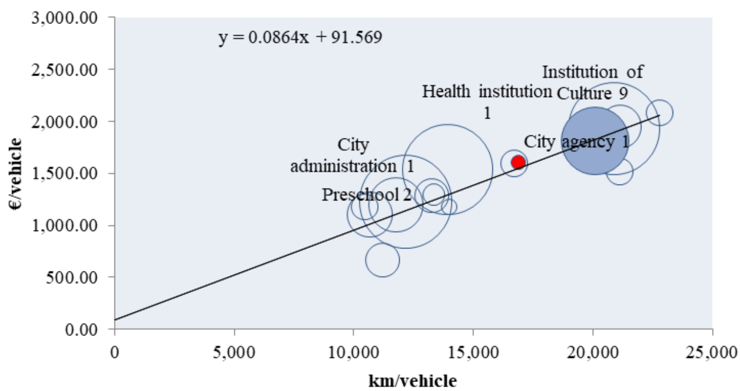

Figure 9. After the implementation of the measure of establishing a unified fleet (the colored "balloon" is a combined fleet with 20 vehicles)

Expected savings only through the reduction of fixed costs (maintenance, depreciation, registration and vehicle insurance) amounts to at least 50.000 € a year or about 5% of the total energy costs of all observed fleets in 2016. Additional savings can be expected as a result of the fact that the new fleet will be managed centrally, which can eventually be established as a new example of good practice in fleet management in public institutions in R. Serbia.

When the measure comes to life, other vehicles can be connected to the joint fleet, in the first place, the City Administration fleet should become a part of the joint fleet. Additionally, this measure has strong marketing potential, so the City should, with its example, lead the citizens to a new way of thinking in the direction of reducing the number of vehicles, reducing parking space burden, promoting car sharing, etc.

Furthermore, public institutions can improve the state of the so-called joint driving to work and to the most frequent destinations (eg. often conducted trips to Belgrade) as well as "pairing" their employees' driving with appropriate information and tools based on sharing information via the Internet or intranet.

The repayment period depends on the modality of the implementation of this measure. If a new fleet would be formed from existing vehicles, the costs would be due to the need for software and hardware for telematics. The assumption is that these costs would be compensated by selling the surplus vehicle (41 vehicles). In that case, a gradual transition to newer vehicles could be made, thus further improving the quality of the fleet.

It is expected that the repayment period will be very short, shorter than 3 months, which should be confirmed through a feasibility study.

4.3 Measure 3: Establishment of eco-driving programs in the City Administration

The measure involves the launching of eco-driving training programs for drivers employed by public companies who, because of the nature of their work, exceed a certain number of kilometers per year because eco-driving training is the easiest way to pay off for high mileage drivers. In accordance with experiences in similar situations, the minimum expected fuel savings is 5% (experiences in practice go up to 20% [4, 5]).

In order to facilitate the acquisition of knowledge and skills (and the likelihood that they will be longer in public enterprises and institutions), it is suggested that younger drivers first go through training. In the companies concerned, 158 persons are employed in the driver's position. 3/4 drivers of 158 high mileage drivers are employed in just three fleets and these three companies spent € 770,000 on fuel per year. If one-third of the drivers (40 drivers) go through one-day training in the next two years, and if price per driver for that program is 100 € per driver/day, and the cost of lost working hours is estimated at about 12 € per participant (based on the average monthly income of 350 euros) it would save 2%, i.e. the savings would be around € 15,000, and the repayment period of the proposed measure would be up to 4 months. Furthermore, we should not ignore the side effects of such programs, such as improved safety, reduced tire, braking systems, and other maintenance costs. In order to measure the results of the proposed measure, it is necessary to combine it with Measure 1. i.e. data collecting. The driver rewarding and stimulation of the desired behavior can be founded from savings, which could accelerate the expected results.

4.4 Measure 4: Tire pressure control

Implementation of this measure should be centralized, by equipping one vehicle with a mobile compressor that would visit all vehicles in existing fleets for two months (325 vehicles in total). Estimated savings range from 0.6% (conservative) to 2% (optimistic) of total fuel consumption [6]. If the compressor is fitted with one of the vehicles withdrawn from the previously processed Measure 2 the investment could be minimal, amounting 300 €. If the operating cost of the operator is 2 €/hour gross and if operator needs 0.5 hours per vehicle, and the price of fuel, registration, insurance, and maintenance of the car amounted to 120 € per month the repayment period would be 6 months according to the most conservative scenario, and two months according to the optimistic scenario. The total estimated savings are € 7,000 to € 22,000 per year.

4.5 Measure 5: Transition of a part of the petrol fleet to liquid petroleum gas

For the implementation of this measure, vehicles and fleets in the M1 category exceeding 10,000 km/year per vehicle should be selected. The approximate cost of installing the device is 450 €, while certification is 100 € per vehicle. The proposed measure covers a total of 120 vehicles with a total of 1,800,000 kilometers in 2016. The expected investment is 66,000 € with a repayment period of up to about one year (at the current price difference between gasoline and LPG, with an average fleet consumption of the said 120 vehicles of 9.3 l / 100 km). The annual savings were estimated at € 110,000 in the case that the measure is implemented on all 120 vehicles. The pace of implementation is subject to adjustment according to the resources available.

5. CONCLUSION

Instead of a conclusion, all expected savings are given in the following table. The abovementioned measures are characterized by short payback periods and could result in a relatively large saving of energy if measures are conducted consistently.

Description	Investment (€/year)	Potential savings (as % of the energy used in 2016)	Expected savings (€/year)	Simple payback period (years)	Priority level
Data collection, internal benchmarking, transparency, the publication of collected information and rewarding of good practice examples	**low**	**3%**	**30.000**	**short**	**1**
Creation of a joint fleet, joint driving and driving pairing (car sharing in public institutions)	**depends on implementation strategy, it can be low**	**5%**	**50.000**	**less than 3 months**	**1**
Establishment of eco-driving programs in the City	**4.400**	**2%**	**min 15.000**	**less than 4 months**	**2**

Administration					
Tire pressure control	**3.500**	**2%**	**min 15.000**	**6 months**	**2**
The transition of a part of the petrol fleet to liquid petroleum gas	**66.000**	**Up to 10%**	**110.000**	**one year**	**3**

Since there is no energy efficiency program ongoing, expected total energy savings are estimated as (relatively large) 22%. This number is suggesting both: a large space for energy management measures and that fleets are relatively poorly managed up to date. Here proposed approach is characterized by transparency, easy adaptation, and opportunities to monitor and follow the results of the implementation of proposed measures.

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TOUCH SCREEN CAR DASHBOARDS AS SERIOUS DANGER FOR CAUSING TRAFFIC ACCIDENTS

Janez Kopač [1], Franci Pušavec [2]*

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RESEARCH ARTICLE

ABSTRACT: More and more sophisticated cars have also very modern cockpit boards full of information, with many buttons, touch-screen interactions, commands on steering wheel, radio, A/C, etc. We know how dangerous alcohol is and its influence on prolonging driver's reaction time. In recent years, there is also a strong action against using a phone during driving. Searching through the phone menu is taking attention off the road. Similarly, drivers with new cars need several months to learn approximately where particular/some commands can be found. We have measured time periods necessary to find different commands. For example, activating A/C takes 1.0 s -2.0 s. In the case of car moving with speed of 50 km/h through the city, this means traveling along a path of 14 m – 28 m without any control (by speed of 120 km/h, this corresponds to 33 m – 66 m). Additional fact is also the existence of a red triangle emergency button that is becoming smaller and smaller and thus poorly visible in new cars. To find this button, driver again needs more than one second in most critical situations, when full concentration focused on the road is needed. This paper presents different car dashboards and measured necessary times for obtaining control. Results are followed by discussion and the suggestions to the drivers how to deal with the raised problem.

KEY WORDS: cars, dashboard, control buttons, touch screen, lost time, reaction path

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[1]*Janez Kopač, PhD prof., University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva c. 6, 1000 Ljubljana, janez.kopac@fs.uni-lj.si (*Corresponding author)*
[2]*Franci Pušavec, Assoc. prof., University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva c. 6, 1000 Ljubljana, franci.pusavec@fs.uni-lj.si*

INSTRUMENTALNE TABLE AUTOMOBILA SA EKRANOM OSETLJIVIM NA DODIR KAO VAŽNA OPASNOST ZBOG IZAZIVANJA SAOBRAĆAJNIH NEZGODA

REZIME: Sve više sofisticiranijih automobila takođe poseduju veoma moderne table za pilotske kabine pune informacija, sa mnogo tastera, interakcije sa dodirnim ekranom, komande na točku upravljača, radija, klima uređaja itd. Znamo koliko je opasan alkohol i njegov uticaj na produženje vremena reakcije vozača. Poslednjih godina je takođe snažna akcija protiv upotrebe telefona tokom vožnje. Pretraga kroz meni telefona skreće pažnju sa puta. Slično tome, vozačima novih automobila potrebno je nekoliko meseci da nauče otprilike gde se mogu naći pojedine komande. Izmerili smo vremenske periode potrebne za pronalaženje različitih komandi. Na primer, za aktiviranje klima uređaja potrebno je 1,0 s - 2,0 s. U slučaju da se automobil kreće brzinom od 50 km/h kroz grad, to znači da se kreće stazom od 14 m - 28 m bez ikakvog nadzora (brzinom od 120 km/h, to odgovara 33 m - 66 m) . Dodatna činjenica je i postojanje crvenog dugmeta za hitne slučajeve koji je sve manji i manji, a samim tim i slabo vidljiv u novim automobilima. Da bi pronašao ovo dugme, vozaču ponovo treba više od jedne sekunde u najkritičnijim situacijama, kada je potrebna puna koncentracija usmerena na put. U ovom radu su prikazane različite komandne table automobila i izmerena potrebna vremena za dobijanje kontrole. Rezultate prati diskusija i sugestije vozačima kako da se izbore sa postavljenim problemom.

KLJUČNE REČI: automobili, komandna tabla, kontrolni tasteri, dodirni ekran, izgubljeno vreme, reakcije puta

TOUCHSCREEN CAR DASHBOARDS AS SERIOUS DANGER FOR CAUSING TRAFFIC ACCIDENTS

Janez Kopač, Franci Pušavec

1. INTRODUCTION

The study on the use of mobile phones by the drivers shows problematical situations in using them during driving. As an answer to the safety issues, there appear some alternatives like: driving mode on the phone allowing just incoming calls, hands-free installation in the car, voice commands, etc. Even though they have their advantages, none of those solutions assures a 100% safe usage of the phone during driving. Still, in most cases, this is not serial equipment of the car - many drivers still hold mobile phones simply in hand, without any hands-free connection with car radio system. On one side, this is taking their attention from the road to the phone. However, at least they normally hold the phone between the head and the steering wheel. In this way, they partially see the road and traffic in front of them. This is not perfect, but still much better than searching/typing on the touchscreen located on the right side of the driver, thus the driver must physically look away for approximately 35^{o} from the direction of driving. This means losing the attention from the road for 1.0–2.5 s. Depending on the driving speed, this time corresponds to the path that car drives without attention of the driver [4].

In addition, the important dilemma has been raised related to the question how many commands it is really necessary to have on the dashboard and which of those can be really adjusted during driving? However, the trend seems to go in other direction. The dashboards in new cars are going to be totally digital in parallel with the request from EU commission to assure higher traffic safety.

The new developed cars are going to be completely autonomous with a lot of electronic support/active supervision systems: active adaptive cruise control/breaking system, road line assistant, speed assistant, etc. Those systems are adding a stone to the traffic safety. However, it will take a long time (approx. 20 years) for all cars to be equipped with such technology. Basically, it is going to take the car lifetime. Just after the old cars will reach their lifetime, they will be changed with the modern ones.

2. SOME CASES OF COCKPITS AND THEIR SPECIFICATIONS

A multifunction steering wheel, equipped with 4+1 different control handles, offers wide control options. However, the number of control varieties is also enhancing the complexity and time to adjust lights, gear transmission, cruise control, windshield wiper, etc. Advantage of a cockpit shown in Figure 1 is a big digital speed display and a big button for switching the warning emergency lights, in the middle of a dashboard pillar. However, simple search for air circulation control can then take a lot of time. It can be expected that the driver spends 1-3 s for this action. Figure 1 shows an example of a very transparent speed indicator on top positioned display that offers no need to search downwards and to the right side, but it is directly in the line of the driving direction.

Figure 1. Cockpit of car A with many options - all functions are activated by mechanical switches/buttons

On the contrary, Figure 2 shows the steering wheel with many commands that is obstructing the view of the dashboard.

Figure 2. Cockpit of car B with many controls on the steering wheel obstructing the view of the dashboard

In the case shown in Figure 3, during driving with speed limit (for instance, in the city, where speed limit is 50 km/h), the average time for adjusting the most common settings in the car amounts between 1.5–2.0 s [3]. This confirms the suspicion that the modern cars offer a lot of command possibilities with the drawback in attention that has to be taken from the road and, in most cases, put on the touchscreen commands for a couple of seconds. One of the solutions that would help improving this issue could be in the system for track control by video sensing system.

Figure 3. Cockpit of car B with digital dashboard

Some modern cars even have many more systems, equipment, commands, mechanical switches and touchscreen commands. It is a fact that being able to control all of them takes time to recognize them, remember and scroll their positions. Especially, searching the position of the desired command during driving can be very dangerous. It is well known that, in sophisticated cars, drivers need to drive them for 50,000 km or use them for 2 years, before they are completely comfortable with their usage and are even capable to automatically use some of the commands, without removing the attention from the road [1, 5]. Even the emergency buttons – triangular buttons for blinking lights can be problematic. In Figure 4, two options are presented: the conventional command panel (right) and the touchscreen command panel (left). In addition to the aforementioned differences, a comparison between triangular emergency blinking lights switches is interesting. It seems that, with modern cars, the size of this switch is decreasing. This should not be the case, because it is clear that this switch can be used in the most critical situations, where size should not influence the critical moments. In extreme cases (Figure 5), modern dashboards can even be made so that there is not a single button switch present any more.

Figure 4. Comparison of B (left) and A (right) car cockpits and ease of access to the triangle warning button

Figure 5. Totally digital dashboard as an answer to request for higher traffic safety

3. CONCLUSION AND FURTHER RESEARCH

“Principle of Trust” between the drivers on the road is actually stronger then between husband and wife in the family. Drivers are driving against each other on a narrow roads, with speeds up to 90 km/h. In the case of an accident, this would present the impact speed that is double, i.e. 180 km/h. In other words, such speed corresponds to the approaching path of 50 m in every second [2]. In such cases, every tiny part of a second that the attention of the driver is lost from the traffic by checking instruments on the dashboard can be crucial/critical. On normal roads, traffic lanes are narrow and they can have 2.5 m of width. In such cases, with attention not on the road, car can reach the opposite lane in approximately 0.5 s, if the steering wheel deviates 10^o from the direction of the road. Thus, in the case when belief, trust and attention are not present, even luck can hardly prevent occurrence of a car crash. Modern cars will in those critical situations help a lot with indication of critical moments, with automatic breaking, etc. However, attention of the driver to the traffic is and will always be the most important parameter rescuing the critical moments that can happen in the traffic.

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WILL ELECTRIC MOTOR SUBSTITUTE INTERNAL COMBUSTION ENGINE?

Dušan Gruden[1*]

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RESEARCH ARTICLE

ABSTRACT: The first transportation means driven by a DC electric motor was a six-passenger boat. Ground vehicles with electric drive have also a longer history than vehicles with IC engines. At the beginning of the 20th century, there were more cars driven by electric motors then those driven by IC engines. During the last 100 years, there have been many attempts to replace the IC engine with supposedly better power units. Experiments with electric vehicles were repeatedly performed. Around 1.1 million electric vehicles or about 0.12% of 947 million of passenger vehicles is used in the world traffic today. In terms of CO2 emissions, electric cars have an environmental advantage after 2 to 4 years of use, only if the electricity for their charging is created by regenerative sources: water, wind, solar energy, high and low tides or nuclear energy (as in France). In China and Germany, where the largest part of the electricity is produced in the coal or gas power plants, the CO2 emissions created by electric cars are significantly higher than those created by cars with IC engines are. It is the opinion of many experts, that vehicles with combined drive via an electric motor and a single, relatively small and optimized IC engine (so-called hybrid drive), present the best solution passenger cars in the future, especially in terms of reduction of toxic emission in the cities, as well as in reduction of fossil fuels consumption. The conclusion of this analysis of electric drives for motor vehicles, can only state the same as it repeats for over half a century: "The piston IC engines will be substituted by the better powertrains during the following 10 to 15 years and the existing oil reserves will be spent in the next 30 to 40 years!"

KEY WORDS: fuel cells, hybrid vehicles, electric vehicles, ecological fuels, IC engine

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[1]*Dušan Gruden, PhD prof., Technical University of Vienna, Karlsplatz 13, 1040 Vienna, Austria, former director of Engine development and Sector for ecology end energy at Porsche, Stuttgart, gruden@yudit.de (*Corresponding author)*

DA LI ĆE ELEKTROMOTOR ZAMENITI MOTOR SA UNUTRAŠNJIM SAGOREVANJEM?

REZIME: Prvo prevozno sredstvo pogonjeno jednosmernim električnim motorom bio je čamac sa šest putnika. Kopnena vozila sa električnim pogonom takođe imaju dužu istoriju od vozila sa motorima sa unutrašnjim sagorevanjem. Početkom 20. veka bilo je više automobila koje pokreću električni motori, nego onih koje pokreću motori sa unutrašnjim sagorevanjem. Tokom poslednjih 100 godina bilo je mnogo pokušaja zamene motora sa unutrašnjim sagorevanjem navodno boljim agregatima. Eksperimenti sa električnim vozilima su više puta izvedeni. U svetskom saobraćaju danas se koristi oko 1,1 milion električnih vozila ili oko 0,12% od 947 miliona putničkih vozila. Što se tiče emisije CO_2, električni automobili imaju ekološku prednost nakon 2 do 4 godine korišćenja, samo ako se električna energija za njihovo punjenje stvara iz regenerativnih izvora: vode, vetra, solarne energije, visokih i niskih oseka ili nuklearne energije (kao u Francuskoj). U Kini i Nemačkoj, gde se najveći deo električne energije proizvodi u elektranama na ugalj ili gas, emisije CO_2 koje stvaraju električni automobili značajno su veće od onih koje stvaraju automobili sa motorima sa unutrašnjim sagorevanjem. Mišljenje mnogih stručnjaka je da vozila sa kombinovanim pogonom preko elektromotora i jednim, relativno malim i optimizovanim motorom sa unutrašnjim sagorevanjem (tzv. Hibridni pogon) predstavljaju najbolje rešenje putničkih automobila u budućnosti, posebno u pogledu smanjenja toksične emisije u gradovima, kao i smanjenju potrošnje fosilnih goriva. Zaključak ove analize električnih pogona za motorna vozila može reći samo ono što se ponavlja više od pola veka: „Klipni motori sa unutrašnjim sagorevanjem biće zamenjeni boljim pogonskim sklopovima tokom sledećih 10 do 15 godina i postojećim rezervama nafte biće potrošeni u narednih 30 do 40 godina!"

KLJUČNE REČI: gorive ćelije, hibridna vozila, električna vozila, ekološka goriva, motor sa unutrašnjim sagorevanjem

WILL ELECTRIC MOTOR SUBSTITUTE INTERNAL COMBUSTION ENGINE?

Dušan Gruden

1. INTRODUCTION

In the world, and particularly in Europe, an intense discussion is being lead today about the need to forbid the use of internal combustion engine (IC engine) because it, allegedly, has only negative consequences on human environment. Representatives of the Green party in Germany are seeking a ban on the IC engine from the year 2030 in their program, while their counterparts from the Social-democratic party demand this ban from 2040. French writer and philosopher Andre Marlo wrote: “Who wants to predict the future, must first go through the past”!

2. SHORT HISTORY OF ELECTRIC VEHICLES

The first transportation means driven by a DC electric motor was a six-passenger boat, patented by Morris Herman von Jacobi in 1838, trying his own boat on the Neva in Saint Petersburg, Russia [1]. Ground vehicles with electric drive have also a longer history than vehicles with IC engines. As early as 1881, five years before the first motor vehicles arrived, which are attributed to Daimler and Benz in Germany, an Englishman, Gustav Truve, have built in the electric drive on a tricycle. In 1898, Gaston Šezelup-Labat laid the first car speed record. With a car with electric drive, he achieved a speed of 63.12 km/h. In 1890, the carriage maker from Vienna, Ludwig Lonner, gave an order to the young engineer Ferdinand Porsche to develop a cab, which would be powered by the electric motor. At the world exhibition in Paris in 1900, Porsche and Loner presented their patent: vehicle driven by electric motors built-in on its wheels, so that each wheel had its own drive, Figure 1.

Figure 1. Loner-Porsche electric vehicle at the World exhibition in Paris in 1900

At the beginning of the 20th century, there were more cars driven by electric motors then those driven by IC engines. In that time, the forecasts for the future of the cars with electric drives were significantly more optimistic than for cars with IC engines. Back in 1910, over 30% of cars in the traffic in the US were electric cars. Accumulation (storage) of electricity in these cars was carried out exclusively in so-called lead (Pb) accumulators – batteries. Their great weight, for any larger energy capacity of battery, and the long time it takes to charge the battery, were the biggest shortcomings of those cars. At that time, passenger vehicles with electric motors could develop speeds of around 100 km/h and had a range of about 70 to 100 km. The rapid development of IC engines, especially after the invention of the electric starters for engines, where the lead electric car battery as a power source for the start-up have been applied until today, has begun to suppress electrical drives, first of all in passenger vehicles. The culmination of application of electric drives, especially in the field of freight transport, was reached between 1920 and 1930. To minimize the main disadvantage of electric vehicles - their small driving radius, so called hybrid drives or vehicle drives with two engines - electric motor, consuming the electric power from lead batteries, and IC engine, which drives a generator to produce electricity for charging the battery, were offered at the beginning of the 20th century, Figure 2. The first hybrid car of that time was a Ford (1912).

Figure 2. The first hybrid vehicle

High production costs for these vehicles prevented their wider application. The electricity, similar to the heat, has a feature that it has to be consumed the second when produced, because its storage is not simple, but very difficult and complicated. In vehicles which are directly connected to a source of electricity, like in rail transportation, trams and trolley buses, electrical drives are established for decades, with all their advantages.

3. STATE OF THE ART IN DEVELOPMENT OF VEHICLE POWER UNITS

Since 1920s, until today, piston internal combustion engines (IC engines) have become the undisputed drive unit, not only for passenger cars and freight vehicles, but also for a wide range of other different applications. The IC engine owes this wide distribution to its characteristic that it uses one of the biggest and the cheapest energy sources of the planet Earth, namely oil, with greater efficiency than other power units. During the last 100 years, there have been many attempts to replace the IC engine with supposedly better power units. Experiments with electric vehicles were repeatedly performed. From the 1980s, the attempts in Mendrizi (Switzerland), Berlin (FR Germany), La Rošelu (France) and Amsterdam (the Netherlands) were well known. In the early 1990s, extensive testing of electric cars were conducted on Reagan island in the Baltic Sea (FR Germany), with always the same conclusions: main problems are the storage, accumulation of electric power in batteries, small driving radius of vehicles and their high production costs. Although different batteries like NiCd (Nickel-Cadmium), NaCl (Sodium chloride), NaS (Sodium-Sulfur) and NaNi (Sodium-Nickel) were tested at that time, the lead (Pb) battery has always been the winner, despite all its faults. Its energy capacity is around 70 Wh/kg. It takes a lead battery of 3,000 l of volume and 6.5 t of weight for the same amount of energy as in a reservoir for gasoline of 70 l (gasoline 12,000 Wh/kg). The modern lithium-ion batteries (Li-Ion) have an energy capacity of approximately 100 to 250 Wh/kg (250 to 620 Wh/l), that is, in order to replace the energy amount in 70 l of gasoline, they need to have the volume between 400 and 1,000 l and the weight of 0.4 to 2.0 t, Figure 3.

Figure 3. Energy needed for 500 km range of driving

Whether electric vehicles would succeed in this new attempt to break through to a large serial production and replace piston IC engines depends on the further development of accumulator - battery, its production cost and energy charging speed. Until now, passenger vehicles with electric drives have been produced in relatively small numbers. Around 1.1 million electric vehicles or about 0.12% of 947 million of passenger vehicles is used in the world traffic today. The share of these vehicles in the traffic in the USA is about 0.76% and in Germany about 0.38%. These numbers suggest that, until now, the use of the electric vehicles was limited to a small area of application, first in small distance traffic, in the city traffic and as a second or a third vehicle in the household. In the future, vehicles with electric drives would have to satisfy the demands, as complete family vehicles, able to cover larger distances. The key problem of all electric cars is their driving radius. For fast covering of larger distance, not only a distance travelled with one battery charge is important, but also the time it takes to charge the empty battery. Today's standard battery charging is carried out with relatively low or medium-sized power, with the power supply voltage of 110 V or 220 V, and it lasts several hours, similarly to charging Li-ion batteries in mobile phones or laptops. These vehicles should always be charged, when they are not used for a long time, for example at the parking lots or at homes, in garages. To increase the speed of charging to approximate time needed to refuel the vehicles with the IC engines, systems with high power and voltage of 800 V to 1,000 V are being developed, which causes a substantial increase in investment for the design of infrastructure. All consumers of energy in the electric vehicle are supplied with energy contained in the battery. Thus, the driving radius of vehicles with electric drive is greatly influenced by the weather conditions in which the ride takes place (day, night, rain, snow...). Vehicle’s air-conditioning, especially the heating of electric vehicles, can significantly reduce their driving radius, Figure 4.

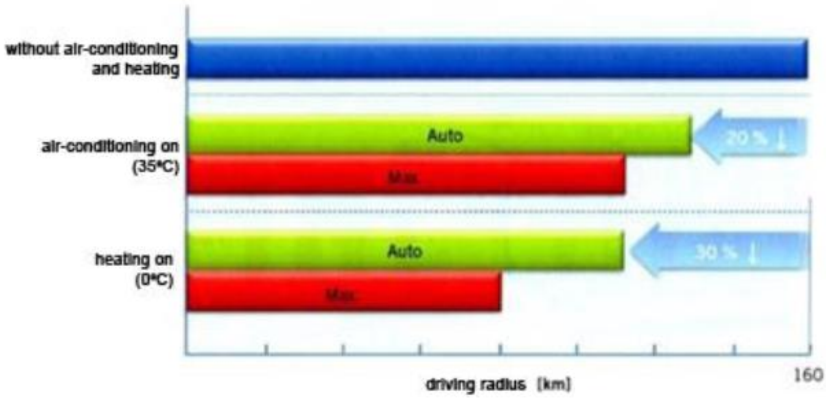

Figure 4. Driving radius of electric vehicles with air-conditioning and heating turned on

The typical battery of the electric vehicle consists of more than 100 cells. In Tesla S car, the battery consists of 16 modules with 7,104 Li-ion cells. It takes only a single cell not to work and the whole system has to be changed. All batteries have certain temperature areas in which they can work optimally. These operating temperatures affect the capacity of the battery (and hence the driving radius), as well as battery life. That is why the so-called thermal management of the batteries is very important. For Li-ion batteries, the optimum operating temperatures lie between 20 °C and 40 ºC. It is often emphasized, that the ecological advantage of electric cars is that they do not emit toxic emissions during their operation. That is true if only those emissions that arise on the path from the battery to the car's wheels are considered (so-called “tank-to-wheel” analysis). However, if one looks at the overall ecological balance of electrical cars, from its construction until the end of his lifetime (the "Life cycle assessment"), then the environmental image of electric cars looks different. While around 5 t of CO_2 emissions arises during the production of one middle class motor vehicle, this emission doubles during the production of an electric car, Figure 5 [4].

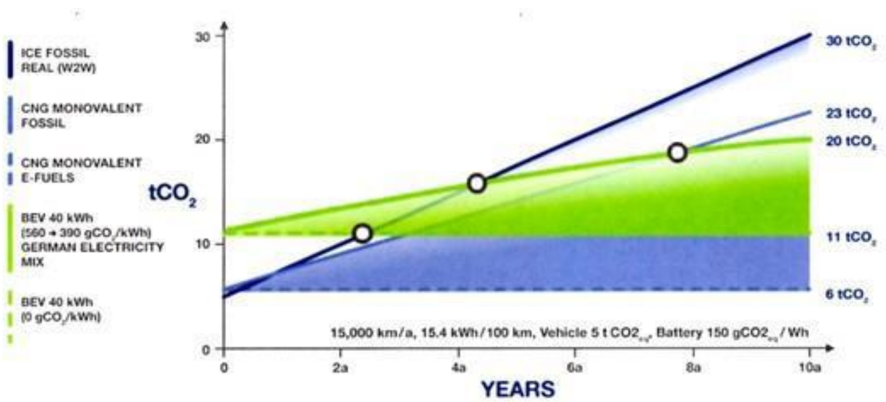

Figure 5. LCA (Life Cycle Assessment) of CO_2 emission (ICE – Internal combustion engine, CNG – compressed natural gas, E-Fuels – ecological fuels, BEV – electric vehicles)

In terms of CO2 emissions, electric cars have an environmental advantage after 2 to 4 years of use, only if the electricity for their charging is created by regenerative sources: water, wind, solar energy, high and low tides or nuclear energy (as in France). In China and Germany, where the largest part of the electricity is produced in the coal or gas power plants, the CO2 emissions created by electric cars are significantly higher than those created by cars with IC engines are, Figure 6.

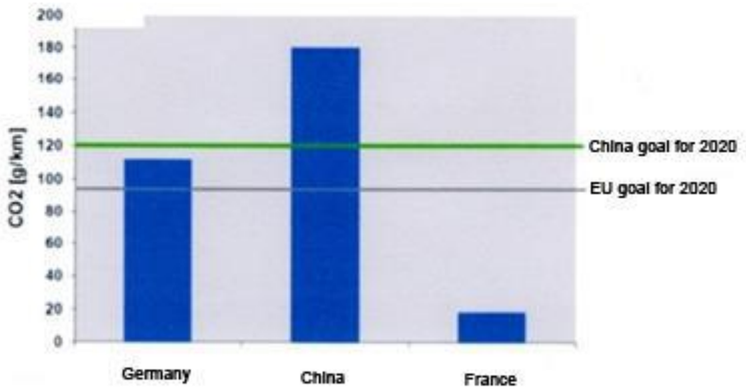

Figure 6. CO_2 emissions of electric car depending on type of electricity production

Today's electric cars with Li-ion batteries cannot meet the European regulations on the recycling of cars. At the end of their lifetime, the passenger cars manufactured by 2015 must prove that 95% of their weight can be re-used or recycled. Only 5% of the vehicle's weight may be deposited on the landfill. With modern electric cars, the weight of Li-ion batteries is approximately 25% to 30% of the vehicle's weight. Until today, solutions for economic reasonable recycling of these batteries have not been found. Also in the area of public and freight transport, there are visible efforts to replace IC motors with electric drives. This drive long ago dominates where there is a direct contact between the transport means and the electricity sources (railways, trams, trolley buses). In some countries, the city transport also contains buses with electric drives, Figure 7. The batteries for these vehicles are charged at terminals over trolleys similar to those on trams or trolley buses.

Figure 7. Electric bus in Belgrade traffic

German industry has suspended work on these projects, because the weight of the batteries is to large, for slightly larger distances that the vehicle would have to pass.

3.1 Hybrid vehicles

One of the biggest disadvantages of electric cars - their relatively small driving radius compared to the cars powered by IC engines, has led to re-development of so-called hybrid cars. With these cars, the features and benefits of the electric drives combine with the positive features of the IC engines. It is the opinion of many experts, that vehicles with combined drive via an electric motor and a single, relatively small and optimized IC engine (so-called hybrid drive), present the best solution passenger cars in the future, especially in terms of reduction of toxic emission in the cities, as well as in reduction of fossil fuels consumption. For years, the hybrid vehicles have become the subjects of huge series production. Out of all the different possible combinations between the electric motors and the IC engines, it looks like a so-called “plug-in hybrid” is the most attractive today. Statistically, one car travels a distance of 30 km to 50 km daily. The goal of the development of the "plug-in” hybrids is to cover the daily distance in everyday traffic with electric drive, because the battery is dimensioned in such a way, that the vehicle can cross this distance. The battery of these vehicles is charged over the normal power supply network (plug-in), at home, or in the workplace. A relatively small IC engine is used in the case when the battery runs out of power, in order to run the generator for the production of electric power and enable the travel over the larger distance. About the half of the so-called electric vehicles in the world are "plug-in" hybrids. How big an advantage the hybrid drive offers compared to pure electric or IC engine drive, can be shown on the example of the Porsche 919 hybrid vehicle [8]. This vehicle have been winning the race on the famous 24 hours of Le Mans race for three years in a row, Figure 8.

Figure 8. The winner of “The 24 hours of Le Mans” race in 2015, 2016 and 2017: Porsche 919 Hybrid

In the area of freight or commercial vehicles and buses, there are also extensive tests with hybrid drives (MAN, Volvo, Iveco).

3.2 Electric drives in water traffic

A historical example of the first vehicle with electric drive from 1838 shows that the electric drive is not connected just to the road vehicles on wheels. For more than 100 years, all submarines have electric (hybrid) drives. After successful deployment of electrical drives on the road vehicles, there are more and more attempts to apply this drive on vehicles in water transport. On many Alpine lakes in Austria, Slovenia, Switzerland and Germany, where it is prohibited to use the boats and the ships with IC engines, vessels with electric drives and with heavy lead batteries are used for decades. New attempts to use electric drives for the ships are associated with efforts to reduce the toxic emissions from exhaust gases of ship engines, especially in large ports, where the emission significantly exceeds the exhaust emission of passenger vehicles. Application of two-stroke diesel engines and the bad quality of the relatively cheap fuels for these engines (heavy oil fractions, mazut) lead to high emissions of sulphur dioxides (SO_2), nitrogen oxides (NO_x) and particulate matter (PM) with these engines. The most attractive electrical drive is for ferries, where the distance between the two ports is not large. The most famous ferry with electric drive is Norwegian ship "Ampera". Its battery pack weighs 10 t [5]. Experts, however, agree that the road to all ships having electric drives is still very long.

3.3 Electric drives in air traffic

The airplane industry is working intensively on the development of quieter, more economical and more environmentally friendly planes. That is why the interest of the industry for the electric powered airplanes is getting bigger and bigger [6]. The best chances are given to the hybrid drive, as the combination of the jet engine and the electric engine. Turbine of the jet engine charges the battery through the generator, during a steady flight at the travel height. At the landing or the take-off of the plane, additional power of the electric engine is used, which reduces airplane noise. The biggest problem here is also the weight of the necessary batteries, because the energy capacity of the fossil fuels (kerosene) is 60 to 100 times greater than the energy capacity of the best batteries today. It is not expected for smaller planes with hybrid drives to take-off and fly in the next 15 years. Bigger airplanes are going to take considerably more time. The hybrid aircrafts are expected to reduce the fuel consumption by 30% until 2035 and by 75% by 2050.

4. A VIEW INTO THE FUTURE

Less than 2% of today’s 1.38 billion vehicles (947 millions of passenger vehicles and 335 millions of commercial vehicles) do not have gasoline or diesel engines, Figure 9. Most of the cars that do not use these two fuels have IC engines that use natural gas (methane) or liquid petrol gas (propane) or so-called bio-fuels (ethanol, vegetable oils). Although the number of the electric vehicles and vehicles with hybrid drives does not exceed 0.12% of the total number of vehicles in the world today, these vehicles are mentioned more in public discussions than all others, as if only they are expected to solve all the problems in the transport.

Figure 9. Modern electric cars (source: ADAC)

Whether the new attempt at introducing electric drives is to be successful, unfortunately, does not only depend on the economic parameters that accompany this vehicle, but also on the political decisions of the governments. The German Government has reached the decision that the number of registered passenger cars with electric drives must be at least 1 million until 2020. Implementation of this decision would mean that, as of today, more than 20,000 electric or hybrid cars must be sold per month, which is far from the actual sales, which is 10 to 15 times lower. What is interesting is that only about 15% of the registered electrical cars in Germany is in private ownership. The largest part is found in larger companies (e.g. post offices) or in the shop windows of the shopping centers.

4.1 Fuel cells

The biggest drawback of electric vehicles - a small energy capacity of the batteries, has found the solution in part through the so-called hybrid drive, where optimised IC engine is applied to drive electric generators. As the IC engine also produces unwanted emissions of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), unburnt hydrocarbons (HC) and particulate matter (PM), during its operation, there are proposals to replace the IC engine with so-called fuel cell. A fuel cell, whose working principle was patented by Englishman William Robert Grove back in 1839, operates on reverse electrolysis principle, Figure 10. While, in the process of electrolysis, water dissolves into hydrogen (H_2) and oxygen (O_2) with the help of electricity, in the fuel cell, hydrogen combines with oxygen, so the electric power, the heat and the water vapour (H_2O) are produced. The electric power is used either directly to drive the electric engine of the vehicle or to charge the batteries.

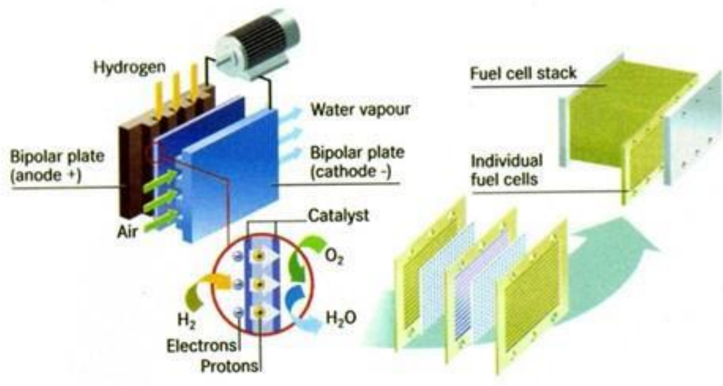

Figure 10. Energy from air and hydrogen: the principle of the fuel cell

Until now, hydrogen (H2) is the only fuel that allows the operation of fuel cells for cars. Although the forecasts for fuel cells were very optimistic at the beginning of this century, this drive so far has not asserted itself on the world market. The only market vehicle with the fuel cell is Toyota-Mirai, Figure 11.

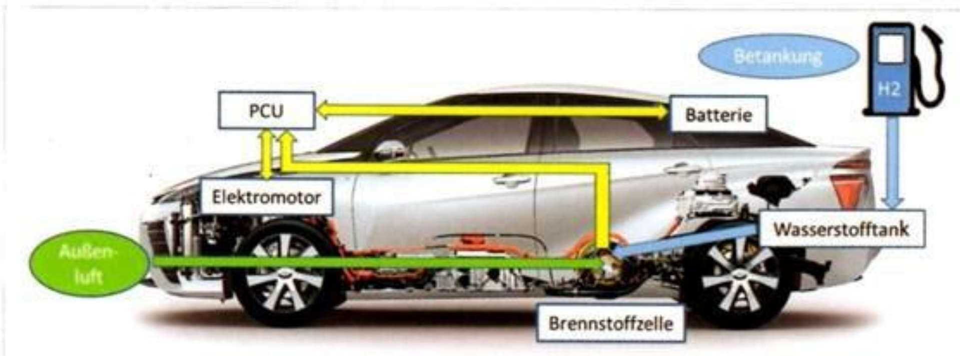

Figure 11. Toyota Mirai with fuel cell

Many believe that, with the development of the battery for the accumulation of electricity, the fuel cells become redundant, because, in order to obtain hydrogen (theoretically the best way is by electrolysis of water), a large amount of electric power is needed. The biggest problems with hydrogen are with its storage, transport, or the absence of entire infrastructure. In the fuel cell, the hydrogen is then used as a source for the production of electricity. The question is why the power would not be directly used for charging the battery, instead through the hydrogen or the fuel cell. One of the leading companies in the field of fuel cells, the Daimler, has moved the focus of the research from the fuel cells to the development of batteries for the accumulation of electrical energy [7]. It is often said that the fuel cells do not have a negative impact on the human environment, because they do not emit other harmful substances beside water vapour (H_2O). Today, the hydrogen, which is mainly used for industrial purposes, is almost exclusively (96%) produced from fossil fuels (natural gas, petroleum, stone coal) with the releasing of the large amounts of CO_2. Carbon dioxide (CO_2) is almost exclusively mentioned during the discussion about the effects of greenhouse gases on the climate change. It is forgotten that the water vapour (H_2O) has the greatest share in the natural greenhouse effect and thus has a threefold greater influence on that effect than carbon dioxide. There is no thought yet about the effect the water vapor will have on the environment if all the vehicles were to transfer from fossil fuels to hydrogen.

4.2 E-*(ecological) fuels*

In parallel with the intense work on the development of electric drives for vehicles, the automotive industry is also working on the further development of the IC engine and, together with the oil industry, also on the development of new, ecologically better fuels. Above all, they include liquid fuels (alcohols, vegetable oils) that are obtained from renewable sources or from the waste. These fuels have the advantage that they can immediately be applied on the existing vehicles, as well as use the existing infrastructure. Hydrogen is also an ecological fuel, which is very good fuel for IC engines and the engines that can successfully consume it were developed a long time ago.

5. CONCLUSIONS

Writing this paper in Detroit, one of the centres of the world automotive industry and observing the daily traffic of thousands of cars with which the workers travel from their homes to work and back, and looking at the dimensions of this continent, I wonder how long will it take for this traffic to cross to the electric drive. From the aspect of densely populated European cities, the discussions about the electric cars have an entirely different dimension, than on this continent. Probably, it is similar in Russia (Siberia is also Russian land), Brazil, India, Australia, China... Well-built infrastructure for recharging the batteries is considered as one of the key issues for the success of the electric cars, in addition to their price. The developing countries will not be able to build this infrastructure and will be related to IC engines for a long time. Wealthier people in the USA are buying the car, which bears the name of the famous scientist, Tesla, showing their commitment to the conservation of nature. There is no mention of the fact that their private, heated swimming pools, the air conditions in their villas, numerous electrical and electronic devices with continuously turned on stand-by lights, boats and ships, consume more energy and emit more $_{CO2}$ than their cars with IC engines. All of the world's cars and commercial vehicles transport is responsible for less than 13% of the total anthropogenic (i.e. of man created) CO_2 emissions. The largest source of these emissions are electric power plants for electricity generation, whose share ranges from 25% to 40% [10]. Behaviour of the countries -producers of oil has considerable effect on the success of the electric drive in the large series production. Lowering the price of oil, whenever there was a danger of its replacement, has eliminated all the efforts for the development of alternative powertrains and alternative fuels. The conclusion of this analysis of electric drives for motor vehicles, can only state the same as it repeats for over half a century: "The piston IC engines will be substituted by the better powertrains during the following 10 to 15 years and the existing oil reserves will be spent in the next 30 to 40 years!"

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TURBULENT DEVELOPMENT OF BODY CONCEPTS, MATERIALS AND JOINING PROCESSES IN THE LAST TWO DECADES

Josip Vlahović [1]*

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RESEARCH ARTICLE

ABSTRACT: Great changes of the car-body Production concepts in the last few years are the result of a rapid development of the new materials, new Joining processes and a new body-concepts. In the last two decades noticeable are big tendencies/aspirations (we can even say fights) for primacy of aluminum. That made it possible a many of new this competition resulted in development of forming methods and many joining techniques which were developed only for aluminum. They are currently in production of about 30 aluminum-cars. On the other hand, today has the aluminum every day more and more share in the new steel car-body-structures. Following the model of the aluminum structures development, there were also attempts to develop similar technological methods for the steel as well. This attempt was not very successful. The real progress has been made with a development of steel specific technologies. It can be said that the advanced aluminium technologies developed in the 1990s, have forced the rapid development of steel technologies as well primarily new Technologies for steel-sheet. It has resulted that the steel relieved, and will be again a cost-effective car-body technology.

KEY WORDS: steel, aluminum, Mg, plastic, carbon

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[1] *Josip Vlahovic, PhD, Freiberg am Neckar, josip.vl@hovic.de (*Corresponding author)*

TURBULENTNI RAZVOJ KONCEPATA KAROSERIJA, MATERIJALA I PROCESA SPAJANJA U POSLEDNJE DVE DECENIJE

REZIME: Velike promene koncepata proizvodnje karoserije automobila u poslednjih nekoliko godina rezultat su velikog napora razvoja novih materijala, novih procesa spajanja i novih koncepata karoserija. U poslednje dve decenije uočljive su velike tendencije (može se reći i borbe) za primat aluminijuma. To je omogućilo da mnogi iz ovog takmičenja razviju metode oblikovanja i mnoge tehnike spajanja koje su razvijene samo za aluminijum. Trenutno se proizvodi 30 modela vozila od aluminijuma. S druge strane, danas aluminijum svakodnevno ima sve veći udeo u novim konstrukcija karoserije od čelika. Prateći model razvoja aluminijumskih konstrukcija, bilo je pokušaja da se razviju slične tehnološke metode i za čelik. Ovaj pokušaj nije bio veoma uspešan. Pravi napredak je postignut razvojem tehnologija specifičnih za čelik. Može se reći da su napredne tehnologije aluminijuma razvijene devedesetih godina prošlog veka naterale na brz razvoj čeličnih tehnologija, kao i pre svega novih tehnologija za čelične limove. To je rezultiralo da se čelik rasteretio, i to će opet biti isplativa tehnologija karoserije automobila.

KLJUČNE REČI: čelik, aluminijum, Mg, plastika, karbon

TURBULENT DEVELOPMENT OF BODY CONCEPTS, MATERIALS AND JOINING PROCESSES IN THE LAST TWO DECADES

Josip Vlahović

1. INTRODUCTION

Development of lightweight bodywork, or to say development of passenger car-body structures, was in the focus of my work within the last 30 years. This can be seen in chart on the Figure 1. Here you can see, at a glance, what happened since the production of the first series aluminum cars in 1903. After a long time of unchanged production of high-volume cars with steel-sheet-metal car-bodies and rare models of aluminum-cars, in 1990s appeared many new technologies, especially for aluminum, which have greatly influenced the way of further development of the carbody- structure. This brought, in the long-standing unchanged steel-sheet-metal production, discomfort and has opened many questions. It caused great changes of the car-body Production concepts. A rapid development of the new materials and new Joining processes has especially supported the rapid development of the production of aluminum cars. It is very interesting that these developments, which went in different conceptual directions, caused big concern for the conventional steel vehicle bodies´ manufacturers. It can be said that the advanced aluminum technologies, developed in the 1990s, have forced the further development of steel technologies as well! Following the model of Aluminum development, the steel bodies manufacturers attempted to develop similar hi-tech methods. This has brought no particular progress, because the technical characteristics of the Aluminum and steel are very different. These improvements can be achieved only through development of steel specific technologies. This challenge resulted in development of so many new appropriate Technologies for steel-sheet cars-body. The results was that the steel vehicles production relieved and will be again a cost-effective option for steel-car-body technologies.

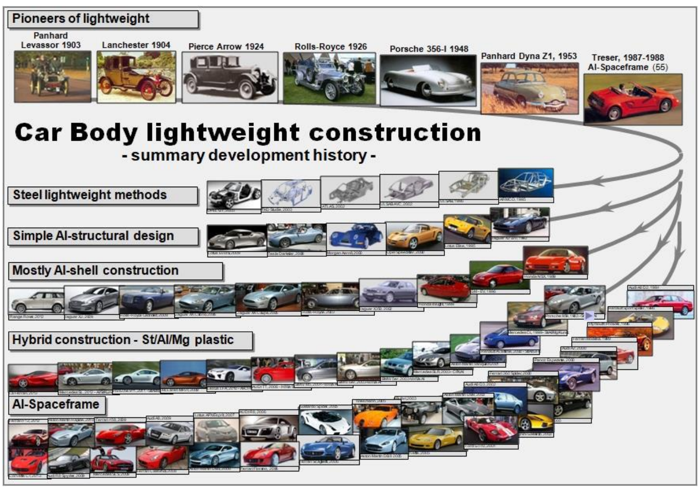

Figure 1. Car Body lightweight history

At the moment, there are in production about 30 Aluminum-cars-bodies. In addition to that the aluminum as a material has every day more and more share in new steel and carbon car-body-structures. It can be said too, there are less and less of the real 100% “Al cars”. The

Aluminum-cars body-structure get steel parts in critical body areas: A/B-pillar and body side structure. The fact is too, that the aluminum-cars-body are being built more and more in hybrid construction method. It is the fact too, that the so-called „steel cars“, are not all made of 100% steel anymore. Large number of new steel vehicles, constantly contain more other materials, mainly aluminum, especially in the crash and the spring connection structures. One-material car-body technologies are slowly loosing dominance!

2. DEVELOPMENT STATUS OF CAR-BODY PRODUCTION - CURRENT STATUS IN THE YEAR 2017

2.1 Total car production per year

Monitoring the production of passenger cars began in the 60's of the last century. In 1969, for example, 22,752 million vehicles were produced. At that time, the total number of passenger vehicles on the road was about 168.7 million. Ten years later the production has reached about 30 million, until 1999 when the production of passenger vehicles reached the figure of 40 million. In the previous year, this number was over 81 million. Drastic growth has been seen since 2005, when China produced 15.25 million vehicles, and in 2017, China produced as much as 24.8 mio with a tendency of growth. The total number of vehicles running in 2015 totalled 947 million, and today this number exceeds one billion. There are different sources stating that the total number of vehicles vary from 1.069 to 1.2 billion. It is well known that from the beginning of the production of passenger cars between 1886 and 2014, some 2.552 billion were produced. This means that 28.8% of them are still on the road.

2.2 What kind of technology we have used in the past?

Developer level techniques, the general economic conditions and the expectation of customers were determining the factors of former mass-produced production of passenger vehicles. It was a simple, reliable and profitable production, which can be generally and briefly described as:

- one construction method - steel-sheet construction
- one type of steel - steel-sheet with different wall thicknesses
- two methods of connection - Spot and MAG welding.

However, the new considerably stricter legal regulations, new environmental requirements and new more demanding customer requirements, caused significant changes in the production of passenger cars.

2.3 What about the current technologies used in car body production today?

As noted above, today we have one complex production of passenger car bodywork in which various materials and methodes have been applied, which result in lighter, safer and more reliable passenger vehicles. These are the basic features of the modern construction of passenger vehicles-car-body: Use of different Body concepts:

- conventional sheet metal construction
- SpaceFrame (profile, cast, sheet)
- mixed construction: sheet-metal, SpaceFrame, monocoque.

Use of different materials:

- Steel, Al, Mg, carbon and other plastic.

Use of different joining technologies:

- different warm and cold joining methods.

3. DEVELOPMENT OF CAR-BODY PRODUCTION TECHNOLOGIES OVERVIEW

3.1 Long time stable car body production

It can be said that since the beginning of the 50s of the last century, when the production of self-supporting car-body began, the production was stable for almost 60 years with little conceptual and technological changes. It was based on the basic principle of a self supporting bodywork, made of steel sheet alone. It was the only construction method, especially appreciated because it is a very fast, cheap, reliable and profitable method due to the extensive automation. Figure 2 presents the main milestones of technological development of conceptual engineering car-body. These are important technical and technological moments which influenced the entire change in the production of the car-body:

- suddenly many Al-cars in mass production
- space frame new construction method
- new different steel classes
- new different joining technologies
- new steel sheet construction methods.

3.2 Suddenly many Al-cars in mass production

Since 1903. until 1987. there was totally 55 different Al-cars in production. Basically, they were small symbolic series until 1953 when Panhard Dyna Z1 in total production from 1953 to 1956 produced 39,460 exemplars. Then there was a small break in the production and development of Al-cars, until 1987. That year, appeared Treser a new unusual Al-car, which was not only in aluminium, but also applied a new concept of bodybuilding. It was the first that implemented the Space Frame concept in a very small series. All that remained without much of attention until 1984, when the mass production of the Audi A8 began, that also implemented the Space Frame concept (Figure 3 and Figure 4). It was the first sign that something new was happening in the car-body production. From 1984 to 2000, 11 Al-cars came into the series. It was only one of the emerging signals for steel car manufacturers that they also have to change something in the long-standing "Long Time stable car body production".

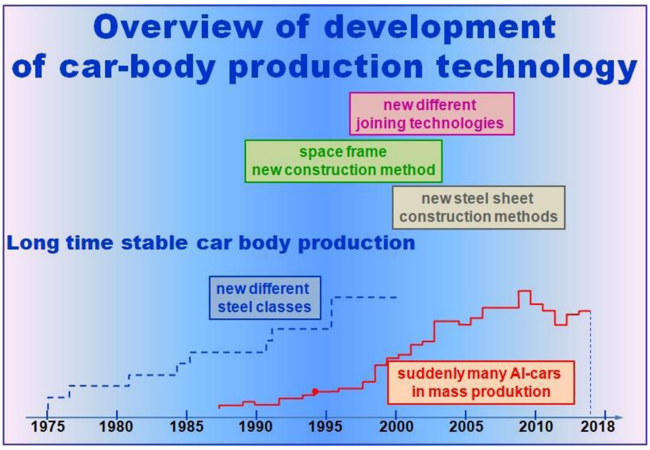

Figure 2. Development of car-body production technologies overview

3.3 Space frame as new car body construction method

With the Audi A8, began mass deployment of this new concept of construction of car bodys. About this concept given in the 90s a lot of talking, researching and experimenting occured. This Al-car-body construction concept is simply described by the following definition: „Space Frame supporting structures are thin-walled spatial structure, whose elements (straight, 2D or 3D curved) have closed sections and in which the nodes of the elements consistently spatially interconnected“ [3]. It is clear that this principle of car-body design has "lightweight" as a leitmotif and as a result of years of work on this topic the following definition was created: „ Lightweight design is a balanced synergy between shape and mass in the available space“ [3]. Today, after almost a quarter of a century of applying this principle, there are visible changes and can be said that slowly the Space Frame car-body concept further developed in the direction of "Multi material" design.

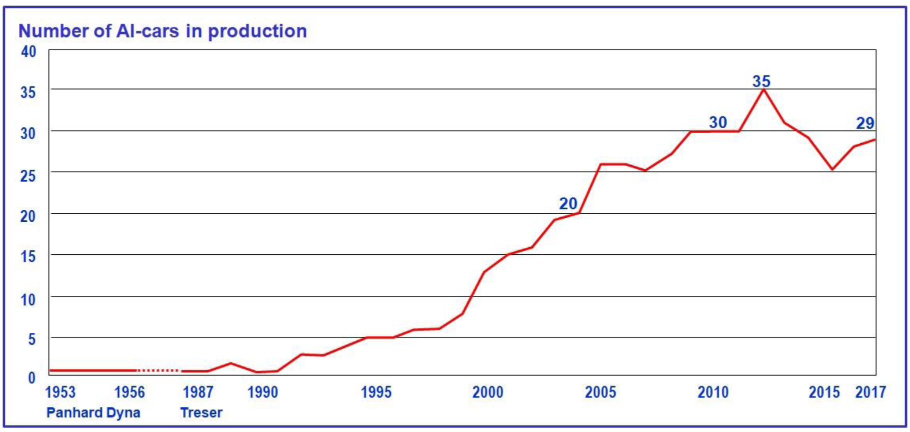

Figure 3. Number of Al-cars in production

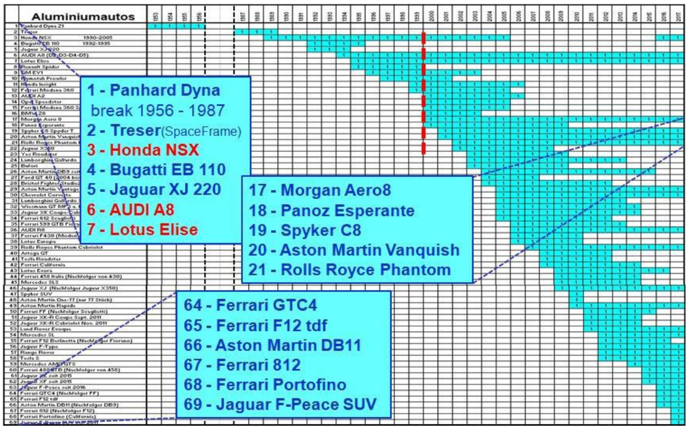

Figure 4. Aluminum cars in production 1953 – 2017

3.4 New different steel classes

It is clear that after major changes in the development of the concept of car-body construction and application of Aluminum as a big competitor to steel, there was a need to make improvements in the quality and the types of steel used as well as in the field of construction method of car-body with steel. So, in the 1990's many new types of steel have been developed, improved both in strength and in the way of forming process.

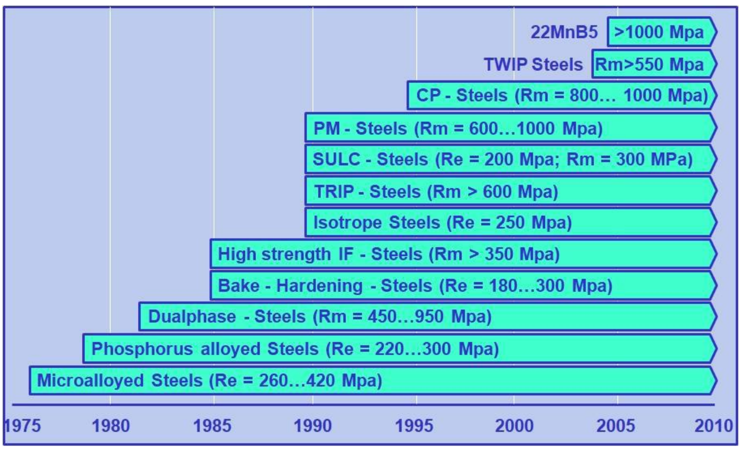

Figure 5. Development of High Strength Steels since 1975 [9]

3.5 New different joining technologies

In the 90's, the development of new "joining" technologies began to appear, especially the so-called "Cold joining methods". Until then, dominating methods were "warm joining" as "spot welding", which were used in the serial production of car-bodies since the 30’s of the last century. At that time the self-supporting bodywork method was patented, based on "steel-sheet" components, as the only profitable, fast and cheap method. Everything started with the development of the basic "Self-piercing riveting" technologies for Aluminum. Today there are two types of this technology: "Semi-hollow and Grip Self-piercing riveting". In order to increase the effect of Selfpiercing riveting, since it is like the "Spot welding" method that results in "Discontinuous body structure", new "Structural adhesive" methods has begun to intensify. So today we have great application of "Self-piercing riveting", but with pre-glued "connecting flange". This results in a "Continuous body structure" which means that all "structural parts" have a full length "closed cross sections". Such approach results in a body-structure with much greater "torsional stiffness". This means that the body structure is much more stable, less vibrating, and ultimately considerably lighter than the body-structure that does not have an adhesive "connecting flange". At the same time, other "cold joining methods", the so-called " Different "Clinch spots" methods, which are used as auxiliary methods, to position the parts before, for example at "Structural adhesive" or before "Roller connection". This method also allows the glued parts to hold and tighten and prevent interference and movement of parts and vibrations. Interestingly, the old simple "warm joining methods", the so-called "Resisting spot welding" for the traditional principle of "steel / alu-sheet" body construction are improving as well. The same situation is with already known methods for steel and aluminum joining, such as MIG, MAG and different Laser welding. Other "cold joining methods" have also been developed, for example: Friction stir welding FSW (cold), Flow drills screws, Tack impact, etc.

3.6 New steel sheet construction methods

In the late 90's of the last century many new steel-sheet construction optimization methods have been developed and perfected so that they can achieve the efficiency of new Al-SpaceFrame constructions. These methods enable "steel-sheet construction" to be significantly stiffer and and lighter and thus remain the dominant "body construction" method. A brief overview of these new methods is shown in Figures 6 and 7. All these methods are based on two simple principles: Tailored & Patch of sheet metal parts.

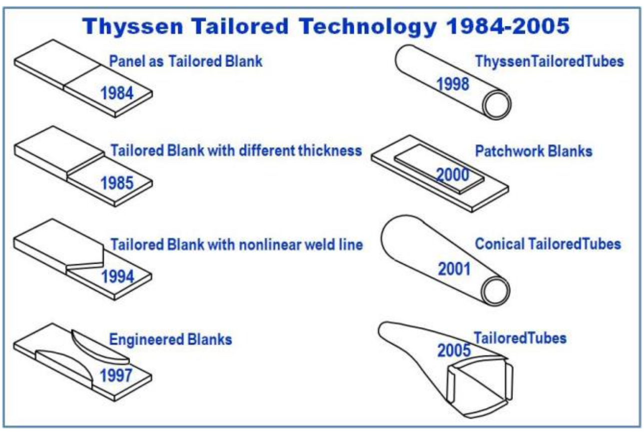

Figure 6. New steel-sheet construction methods – Tailored Blanks [10]

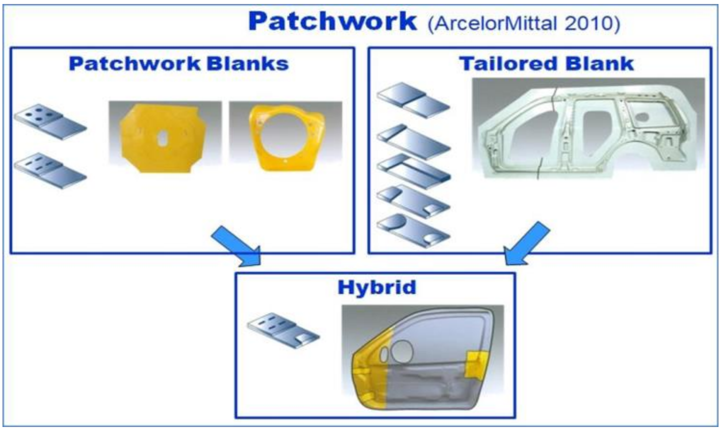

Figure 7. New steel-sheet construction methods – Patchwork [11]

4. COMPARISON OF DIFFERENT MATERIALS AND JOINING TECHNOLOGIES

This is a theme that 30 years ago did not exist, because we have used only "one material and one technology". Today's situation provides a lot more creative possibilities for car-body design and that is why, this rendering as information is very useful (Figure 8).

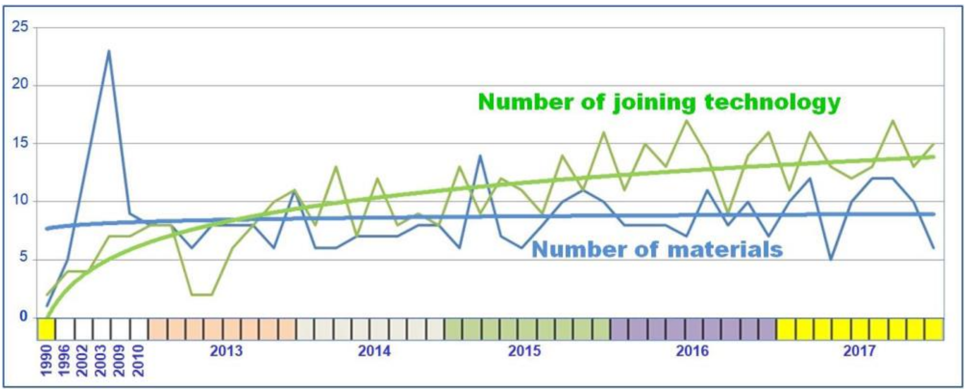

Figure 8. Comparison of number of different materials and joining technologies

If we look in the diagram, we can see significant oscillations on the left part (1996-2013) in the number of applied materials and joining technologies. These oscillations are understandable in the process of searching for the optimum.

It is evident that this number of applied materials, as well as the number of applied joining technologies, have stabilized over time. Talking about an average numbers, one could say that width a new modern car-body (forerunner) there are about 14 different materials and 9 different joining technologies.

5. CONCLUSION - NEW VIEWPOINTS FOR THE FUTURE

All the facts indicate that the times when cars were made from a single steel sheet of various thicknesses have gone, meaning a single material and a single technology is a matter of the past. Neither the method of a single material, introduced with Aluminum, lasted for long. So, the all attempts to produce future cars in new technologies, but from only one material, belong to the past. The data has already shown that we do not have pure "Al-body" today, as well as all the less pure “St-body "except in large-scale daily car manufacturing.

It is clear that new directions are being introduced and that they can be summarized to the following conclusions:

- Most car bodies will still remain made of steel as basic material, but with the introduction of modern processing technology and new materials
- Medium and high class as well as premium cars will have in principle hybrid construction (As today already partially exists) with a basic structure of steel or aluminum, with implementation of other materials and made by introducing modern technologies.
- Exotic sports cars still have the basic structure (as it is to date) from carbon with the addition of other materials and manufacturing technology.

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AN INDICATORS BASED APPROACH TOWARDS DECISION MAKING AND POLICY MAKING REGARDING INTRODUCING ELECTRIC VEHICLES

Kjosevski Stevan [1], Kochov Atanas [2], Kostikj Aleksandar [3]*

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RESEARCH ARTICLE

ABSTRACT: The dynamic development of the societies and cities is significantly based on the role of transport. That means a number of issues need to be addressed in order to reduce emission, keep traffic noise on acceptable level, increase energy efficiency and mitigate long-term threats. One of the solutions is the implementation of electric and hybrid cars. This problem can be solved thanks to the sustainable mobility concept, in which transport needs are limited at the stage of planning spatial development from one side or in implementation of solutions based on electric & hybrid cars. This leads toward research for defining the indicators which would provide information to the policy makers for creating solutions for sustainable transportation and environmental protection. One of the scientific methods used in the research conducted in 6 Western Balkan countries is the AHP methodology and multi criteria decision making process for defining four pillars of indicators, social, economic, cultural, environmental indicators for possible implementation of different types of cars toward the fulfillment of the sustainability goals for the region of WBC's. WBC's as developing countries are still on the first stage in the process of defining indicators for policy making based on scientific methodology.

KEY WORDS: sustainable development, transport, electric vehicle, indicator, policy

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[1]*Kjosevski Stevan, Assistent, University Mother Theresa, Blvd. Goce Delcev 9, 1000, Skopje, R. Macedonia, stevan.kjosevski@gmail.com (*Corresponding author)*
[2]*Kochov Atanas, PhD prof., University "Ss. Cyril and Methodius", Faculty of Mechanical Engineering, Karpos II b.b. P.O.Box 464, Skopje, R. Macedonia, atanas.kochov@mf.du.mk*
[3]*Kostikj Aleksandar, Assoc. prof., University "Ss. Cyril and Methodius" in Skopje, Faculty of Mechanical Engineering, Blvd. Goce Delcev 9, 1000, Skopje, R. Macedonia, aleksandar.kostikj@mf.du.mk*

This paper presents the scientific approach towards decision-making and policy creation for introduction of electric vehicles. The first step, identification of indicators, suitable for the electric vehicles, and developing countries region, has been taken. The paper shows a proposal for indicators on a state/region level, but also such list for personal/company need. The list of indicators is prepared based on wide and deep references analysis, and also on view of big number of experts in the region.

PRISTUP ZASNOVAN NA INDIKATORIMA U ODLUČIVANJU I DONOŠENJU POLITIKE U POGLEDU UVOĐENJA ELEKTRIČNIH VOZILA

REZIME: Dinamički razvoj društva i gradova značajno se zasniva na ulozi saobraćaja. To znači da treba rešiti brojna pitanja kako bi se smanjila emisija, održala buka u saobraćaju na prihvatljivom nivou, povećala energetska efikasnost i ublažile dugoročne pretnje. Jedno od rešenja je primena električnih i hibridnih automobila. Ovaj problem se može rešiti zahvaljujući konceptu održive mobilnosti, u kome su potrebe za transportom ograničene u fazi planiranja prostornog razvoja sa jedne strane ili primene rešenja koja se zasnivaju na električnim i hibridnim automobilima. Ovo vodi ka istraživanju definisanja indikatora koji bi kreatorima politika pružili informacije o stvaranju rešenja za održivi transport i zaštitu životne sredine. Jedna od naučnih metoda koja se koristi u istraživanju sprovedenom u 6 zemalja Zapadnog Balkana (eng. WBC - Wastern Balkan countries) je AHP metodologija i višekriterijumski postupak odlučivanja za definisanje četiri stuba indikatora, socijalnih, ekonomskih, kulturnih, ekoloških pokazatelja za moguću primenu različitih vrsta automobila prema ispunjenju održivosti ciljeva za region WBC's. WBC kao zemlje u razvoju još uvek su u prvoj fazi procesa definisanja pokazatelja za kreiranje politike zasnovane na naučnoj metodologiji. Ovaj rad predstavlja naučni pristup odlučivanju i kreiranju politike za uvođenje električnih vozila. Prvi korak je identifikacija pokazatelja, pogodnih za električna vozila i region zemalja u razvoju. U radu je prikazan predlog indikatora na nivou države/regiona, ali i takav spisak za lične potrebe preduzeća. Lista pokazatelja se priprema na osnovu široke i dubinske analize referenci, kao i na uvidu velikog broja stručnjaka u regionu.

KLJUČNE REČI: održivi razvoj, transport, električno vozilo, indikator, politika

AN INDICATORS BASED APPROACH TOWARDS DECISION MAKING AND POLICY MAKING REGARDING INTRODUCING ELECTRIC VEHICLES

Kjosevski Stevan, Kochov Atanas, Kostikj Aleksandar

1. INTRODUCTION

The world is increasingly talking about sustainable development in the broadest sense and makes efforts to reach it. Transport is one of the largest economic branches globally. This sector has strong impacts on the three main pillars of sustainable development: economic, social and environmental. Also, in accordance with the current trends, it is projected to double the world population of motor vehicles over the next twenty years, and as a consequence, an increase in energy consumption in all regions is expected globally. Knowing that fossil fuels are finite resources and will be exhausted, as well as the need of reduced emissions due to pollution, solutions have been found in the implementation of electric and hybrid vehicles. The need of research for defining indicators to help policy makers create solutions for sustainable transport and environmental protection came to life. The scientific method used in the research is the AHP method and multi criteria decision-making process for defining the main pillars of indicators: economic, social and environmental. Taking into account that the WBC's are developing countries, the identification of the indicators for implementation of electric and hybrid vehicles has been made. The indicators are made to fill the needs on state and regional level as well as for personal and company use. For their use, it is necessary to build a personal and institutional capacity that would guarantee the reduction of risks in making important, costly and farreaching decisions.

2. METHODOLOGY FOR DECISION-MAKING

Making decisions is a complex process that can have far-reaching positive or negative consequences. It is a process of choosing an alternative, from a group of alternatives, in a systematic and logical way. This is why this process has been and is the subject of many scientific researches that result in various methodologies.

2.1 Process of decision making

Making a decision is a process of choosing an alternative, from a group of alternatives, in a systematic and logical way. The basic step by step process used in decision making is called the decision-making process.

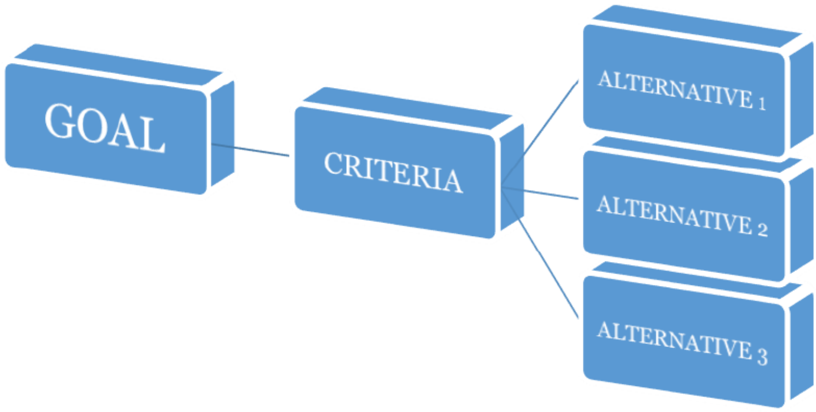

Figure 1. Basic diagram of decision making

The individual steps, as shown in Figure 1, are:

1. Defining the decision-making problem (goal)
2. Identification of criteria
3. Determining the alternatives, etc.

Depending on the type of problem to be decided, there are two types of decision: decision making based on a single criterion and decision-making based on multiple criteria. A decision-making based on multiple criteria is often referred to as Multi Criteria Decision Making – MCDM, [2].

2.1.1 The AHP method

The AHP method is based on the experience of its inventor T.L. Saaty. It is developed in response to the realization that there is a great lack of a general method that is easy to understand and apply, which will allow making complex decisions. Since then, the simplicity and power of AHP has led to its wide application in many domains in every part of the world. AHP has found applications in businesses, governments, social studies, research and development, defence and other areas that involve decisions that require choice, priority, and prediction, [3]. Basically, AHP helps to structure the complexity, measurement, and synthesis of the ranking. These features make it suitable for a wide range of applications. AHP has been tested as theoretically clear, tested on the market and accepted methodology. Its almost universal scalability as a new paradigm for decision making, along with its easy application and understanding make up its success. Moreover, it proved to be capable of yielding results that are consistent with perceptions and expectations.

3. ANALYSIS OF THE CURRENT STATE IN THE WESTERN BALKANS REGION AND DEFINING ITS PROBLEMS

The Western Balkan region covers countries that are not members of the European Union, which at the same time, in the majority, are candidates for its members. In the direction of efforts to become EU members, the countries of the Western Balkans must accelerate their development in a sustainable way. Therefore, the postulates and the mechanisms of sustainable development must be mastered and implemented. Transport, as one of the main components of development, must also be sustainable. The significance of transport is great, not only in the economic pillar but also in the other two main pillars of sustainable development: social and environmental. In this process, politics (governance) and planning have a lot of significance in the process, and more recently the significance of culture which in the region of the Western Balkans brings a series of specifics in relation to that of the older EU members. The countries of the region are conditioned to implement this process and accelerate it in a period of intense technical and technological innovation. Electric vehicles are one of the most typical examples of a complex challenge, given that they are in the middle of multiple pillars of the sustainable development of countries. This arises from several key aspects that are particularly relevant for this region, which by their nature are included in the four groups of SWOT analyses as show in the table below (Table 1).

Table 1. SWOT analysis of the state of transport in the Western Balkans region

Strengths (advantages)	Weaknesses (constraints)
• Road transport, and especially passenger transport, are the dominant segments of the economy and mobility • Electric vehicles are environmentally superior • The performance of electric vehicles continuously improves • The offer of electric vehicles is improving	• The percentage of new vehicles is small compared to the total number of registered vehicles • Electric vehicle prices are too high compared to conventional ones • There are no plans for development of transport in which the potential of electric vehicles is clearly elaborated, as well as strategies for their introduction • It is not clear the connection between the needs and the possibilities of the power system to support the development of a system from fillers • There are no national strategies for the development of electric chargers • There are no national fleet renewal strategies • There is no research on the level of public awareness about ecology • There is no research on the perception of electric vehicles by potential buyers
Occasions	**Threats**
• Large proportion of the population gravitates towards the major urban centers, where most of the economic activities • Large part of the urban transport takes place with passenger vehicles • In recent years there has been a rapid increase in the number of registered vehicles • The condition with the fillers is such that there are only sporadic efforts to place in a limited number of separate locations • The age structure of the vehicle is extremely unfavorable • The level of pollution in urban areas is, as a rule, one of the highest in Europe • The post-sales support of electric vehicles has not yet been built and so on.	• In recent years there has been a rapid increase in the number of registered vehicles • Most of the re-registered vehicles are used with low emission characteristics • A very small proportion of new vehicles are hybrid, an even smaller number are plug-in hybrids, and the smallest number are electric • The condition with the fillers is such that there are only sporadic efforts to place in a limited number of separate locations • The age structure of the vehicle is extremely unfavorable • The level of pollution in urban areas is, as a rule, one of the highest in Europe

3.1 Choosing a scientific research method

The previous chapter of this paper provides a description of the theoretical foundations of multi-criteria decision-making methods. Given that this is a method that will be applied in the field of transport, an additional literature analysis was made, which led to the conclusion that good results from the use of the AHP method can be expected. In the part of the calculations according to the AHP method, several approaches are possible. It can be done with classical calculations, or by using certain software tools, starting from Excel, to special program packages. This research uses the Expert Choice software package. There are more reasons for this. Among them is its availability and the already existing local experience. There are also numerous sources with examples that indicate the compatibility of this software package with the AHP method Expert Choice, with its adaptability to the user, certainly has a great contribution to the success of the AHP method. It includes intuitive user interfaces, automatic calculation of priorities and inconsistency, and several ways to conduct sensitivity analysis.

3.2 Defining Indicators and determining alternatives

The chosen method of research relies on recognizing and selecting indicators. Typically, the stage of choosing the indicators begins with a thorough search of literature. Broadly speaking, the number of papers that in this way analyses sustainable development is very large. Usually, the minimum number of indicators encountered is eight, and the maximum eighty-seven. The average is about twenty-eight indicators. These indicators are mainly divided into segments: economic, social, ecological and institutional, etc [4]. From the analysed literature a selection of nine literary sources was made, which in their completeness and specifics are in direct relation to the topic of the research. From all of them, by analysis and filtering, are extracted the most relevant from a large number of indicators and are organized into groups according to their similarity. In accordance with the AHP method and the way the Expert Choice software package works, it is necessary to choose alternatives whose influence will be analysed in the light of the selected indicators. At the current level of the development of automotive technology, the supply of the market and the presence of vehicles in the traffic, the following alternatives of means of transport were selected:

- Alternative A1: electric vehicles
- Alternative A2: plug-in hybrid vehicles
- Alternative A3: hybrid vehicles
- Alternative A4: vehicles with alternate fuel
- Alternative A5: vehicles with petrol engines
- Alternative A6: vehicles with diesel engines

With the alternatives listed, further research was carried out.

4. USABILITY OF THE RESULTS

4.1 Indicators that can serve to make decisions in the context of the use of electric vehicles

When compiling the list of indicators and their hierarchical placement in the questionnaire that conducted the experimental examination, it started from a thorough review of the literature, with the intention not to make special focus or exclusion of some of them [1]. The consistency and robustness of the results obtained in the ambient of a number of indicators and alternatives, together with the applied scientific method for multi-criteria decision making, make the results of this research more useful in many ways. Their use is possible for making policy assessments from the perspective of central or local government, planning and making corporate, family or personal decisions when purchasing vehicles and the like. If a list of indicators for a narrower and more specific group of respondents is required, or if the need for a decision concerns a number of aspects and alternatives, it is also possible to produce a list of indicators for such a purpose. As a result of the narrowing of the volume of interest, the number of indicators, probably the number of hierarchical levels, will be reduced, and certain indicators will be shifted along the levels. In the area of sustainable transport, in the light of the use of electric vehicles, the number of papers is very limited. Therefore, the identification and selection of research indicators in this context has been accessed in the manner described below. From the analysed literature, a selection of nine literary sources was made, which in their completeness and specifics are in direct relation with the topic of the research. All of them, by analysis and filtering, extracted the most relevant from a large number of indicators and are organized into groups according to their similarity. Then, "condensation, i.e. compression" of similar indicators was made, with more than the literally determined ones being replaced by one. In addition to the indicators that are taken from the literature, indicators are defined and presented, which, according to the techno-economic, social and other aspects, are specific for the use of electric vehicles. Here, above all, is a more detailed expression of individual indicators in order to express the specifics of the particular research. Thus, in the economic indicators are treated the price of vehicles, the costs for their exploitation (range of movement performance) and maintenance, the infrastructural aspects related to the conditions for charging electric vehicles and similar. The group of social indicators detail the elements related to the suitability of passenger vehicles for users with special needs, then the impact of obstacles such as noise and the like. In the ecological group of indicators, adjustments are made according to the structure of the emissions of individual alternative vehicles, noise etc. For the first time (within the information derived from the analysed literature), the alternatives in the column of indicators called culture were made, [1].

Overview of the indicators from the literature and the chosen indicators is shown below:

1. From literature:

- minimal number of indicators is 8
- maximal number of indicators is 87
- average number of indicators is 28.

2. Chosen:

- total number of indicators is 90
- number of hierarchy levels is 5
- indicators at the first hierarchical level: economic, social, environmental, good governance and planning and culture.

The chosen indicators can be used for policy-making as well as decision making on national as well as regional level. Due to overcompensation these indicators are not presented, but are available in the reference number 1.

If a list of indicators for a narrower and more specific group of respondents is required, or if the need for a decision refers to a smaller number of aspects and alternatives, it is also possible to produce a list of indicators for such a purpose. As a result of the narrowing of the volume of interest, the number of indicators, probably the number of hierarchical levels, will be reduced, and certain indicators will be shifted along the levels. Potential examples of the specific scope of the analysis:

1. Analysis of the needs for conducting economic and environmental policies by central or local government;
2. analyses for the needs of making business decisions in the business segment (corporate decisions)
3. analyses for the needs of making personal or family decisions.

As an example of preparing such a separate list of indicators, Table 2 shows a list that could be used in the variant 3.

Table 2. List of indicators that can be used for making personal and family decisions when procuring a new vehicle in the context of sustainable development

Level	1	2	3
Economic	Vehicle prices	Price of a new vehicle	
		Price of second-hand vehicle	
	Type of transport	Urban	
		Suburban	
	Performance	Rank / autonomy	
		Dynamic characteristics	
	Density of electric charging stations / fuel pumps per km		
	Parking	Public	With / without electric charging stations
		Private	With / without electric charging stations
		Work	With / without electric charging stations
	Costs for using a vehicle	Tolls, parking, etc.	
		Environmental tax	
		Maintenance	
	Price of fuel / electricity		
	Costs for capital maintenance		
Social	Mobility	Length and frequency of travel	
	Need for management of a person with special needs		
	Health disorders with exposure to emission and noise		
Environmental	Technical level		
	Emission properties of the vehicle		

5. CONCLUSIONS

The experiences from the conducted research and the results obtained in its separate phases allow for the conclusion of several conclusions, as well as perceiving the needs and directions for further research. Sustainable development and, within that framework, sustainable transport are not only concepts, but also messages for the present and future generations in order to preserve what is inherited from nature and to continuously improve the quality of life of the present and future generations. The literature, as well as numerous documents in this area, are a good basis for further efforts to achieve sustainable transport, and hence sustainable development. Fossil fuels have limited resources and the result of their use is a major contribution to the road vehicles to the air pollution and the environment as a whole. The use of electric vehicles, accompanied by their technical advancement and the development of plug-in hybrids, gives new hope that they can represent an alternative that is more likely to support the development of sustainable transport, that is, sustainable development in the broadest sense. Scientifically based methods for multi-criteria decision making, developed in recent decades, already have validated applicability in different conditions. The AHP method used in this test shows a high level of flexibility and adaptability to the task set. The analysed scenarios for supporting the use of electric vehicles make it possible to assess the potential effect of the usual measures that should also be complex and of a different nature.

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