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ОБЗОРНЫЕ СТАТЬИ

ПРОФЕССИОНАЛЬНЫЕ СТАТЬИ

СОВРЕМЕННОЕ ВООРУЖЕНИЕ И ВОЕННОЕ ОБОРУДОВАНИЕ

CONTENTS

ELECTRODEPOSITION, CHARACTERIZATION AND CORROSION INVESTIGATIONS OF GALVANIC TIN-ZINC LAYERS FROM PYROPHOSPHATE BATHS

Milena D. Stopić[a], *Bernd* G. Friedrich[b]
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Summary:

Tin-zinc alloy deposits are recognised as a potential alternative to toxic cadmium as corrosion resistant coatings. Tin-zinc alloy layers offer outstanding corrosion protection for steel by combining the barrier protection of tin with the galvanic protection of zinc. Tin-zinc coatings have been used on the chassis of electrical and electronic apparatus and on critical automotive parts such as fuel and brake line components. In this study, tin-zinc alloy deposits were successfully prepared from alkaline, pyrophosphate-based electrolytes. The plating process gives a compact and fine grained deposit. The desired proportions of tin and zinc in the deposited alloy are determined by the bath composition and the operating conditions during plating. Three electrode systems were used for the electrochemical investigation. The mechanism of Sn-Zn electrodeposition was studied by linear and cyclic voltammetry. The corrosion parameters, including open-circuit potential-time curves, corrosion potential and corrosion current density of electrodeposited tin-zinc alloys of different compositions have been examined in a brine medium containing 3 wt. % NaCl. The corrosion resistance depends on the plating composition. The Sn-28Zn deposit showed the best anticorrosive properties.

Key words: *electrodeposition, corrosion, galvanic layers, zinc, tin.*

Introduction

Because of outstanding corrosion resistance, tin-zinc layers are mostly used in aerospace, automobile and electrical applications replacing toxic cadmium (Ashiru and Shirokoff, 1996, pp.159-169). The previously used cadmium is not permitted for usage, except for military applications. Additionally, tin-zinc layers have shown excellent solderability and high electrical conductivity.

Because of some disadvantages, the previously mostly used sodium stannate-zinc cyanide plating bath was not widely accepted for industrial applications. In this work, tin-zinc layers were produced in analkaline, non-cyanide, pyrophosphate-based bath. This work contains a description of the synthesis of tin-zinc layers, a detailed analysis of the influence of the deposition parameters and the mechanism of synthesis, a morphological characterization of the formed layers and their corrosion stability. The studied electrolyte contains tin sulphate, zinc sulphate, potassium pyrophosphate as a complexing agent and an additive of gelatine. The formation of tin-zinc layers was performed in a Hull cell. At the same time, X-ray fluorescence was used for a chemical analysis of the electrochemically formed layers. The analyses of the corrosion stability via the open-circuit potential-time curves, the corrosion potential and the corrosion current density of the electrodeposited tin-zinc layers with different chemical compositions have been performed in a brine medium containing 3 wt. % NaCl.

The most important aim of this study was to find a relationship between the process-determining parameters and the characteristics of the electrochemically formed Sn-Zn-layers.

The following partial activities were performed:

• Process design and the analysis of the influence of different parameters on the synthesis of Sn-Zn layers

• Determination of deposition kinetics as well as the stability (corrosion resistance) of the formed Sn-Zn layers

• Investigation of the metal distribution as well as the morphology of layers depending on the chemical composition of the baths used

Synthesis of tin-zinc layers in the Hull cell

The Hull cells are small transportable electrolytic cells. The simulation of different electrochemical processes was mostly performed in the Hull cell. The investigations of electroplating were performed in a range of current density (Andrle and Jelinek, 2007). As the anode plate and the cathode test panel are placed along the non-parallel sides, it is possible to investigate different current densities at the same time in only one performed experiment (Figure 1).

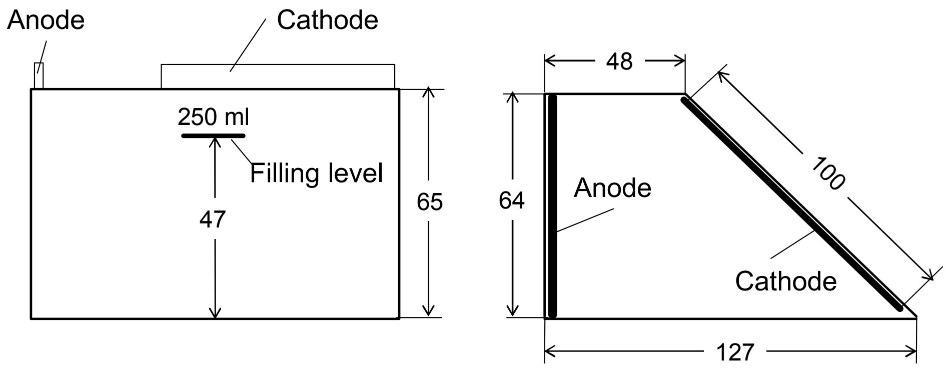


Figure 1 – Principle of work for the Hull cell (Volume of 250 ml)
Рис. 1 – Принцип работы ячейки Хулла(на объем 250 мл)
Slika 1 – Princip rada Hulove ćelije (zapremine 250 ml)

The container of the Hull cell consists of a non-conductive material (e.g., Plexiglas). A brass or steel test panel is usually used as a cathode (cathode dimensions: 0.3 x 70 x 100 mm). The anode material is adjusted to the used electrolyte. As an anode,either a soluble anode based on the material to be coated can be used or an unsoluble anode made from the material such as stainless steel or lead (anode dimensions: 3 x 70 x 65 mm).

Influence of different parameters on Sn-Zn electroplating

• **Influence of the metal ion concentration**

The concentration of alloying elements in an electrolyte has an important influence on the chemical composition of formed coatings (Despic, & Jovic, 1996, pp.239-248). The metal ion concentration in a bath can be varied in three different ways (Vitkova, et al. 1996, pp.226-231):

1. Change of the metal ions ratio, in which the total metal content stays constant

2. Change of the total metal content, in which the metal ion ratio stays constant

3. Change of the concentration of one alloying element, in which the concentration of the other element stays constant

The chemical compositions of the baths studied are given in Table 1.

Table 1 – Variations of the metal and complexing agent concentration in the baths
Таблица 1 – Варианты концентрации металлов и сплавов для покрытия ванны
Tabela 1 – Varijacije koncentracije metala i kompleksirajućeg sredstva u kupatilima

metal content				total metal content		complexing agent	
Sn^{2+}		Zn^{2+}		$Sn^{2+} + Zn^{2+}$		content $P_2O_7^{4-}$	
[mol/l]	[g/l]	[mol/l]	[g/l]	[mol/l]	[g/l]	[mol/l]	[g/l]
0.05	5.9	0.05	3.3	0.1	9.2	0.25	43.5
		0.1	6.5	0.15	12.4	0.375	65.2
		0.15	9.8	0.2	15.7	0.5	87
		0.2	13	0.25	18.9	0.625	108.7

• **Influence of temperature**

The variation of temperature affects the polarization of the electrode and, consequently,the deposition potential. The influence of temperature on the chemical composition of deposited layers and cathodic efficiency was studied at 40°C and 60°C.

Experimental work and procedure

For each experiment, a freshly prepared electrolyte was used. The main components in the bath were metal salts: tin sulphate (as 95.5 % $SnSO_4$) and zinc sulphate (as $ZnSO_4$ * $7H_2O$), as well as potassium pyrophosphate (as 98 % $K_4P_2O_7$) as a complexing agent.Firstly, a volume of 200 ml de-ionized water was put into a glass beaker placed on a heating plate with a magnetic stirrer. After a heating up to 60°C, the complexing agent was firstly added in order to be completely dissolved. Then the metal salts were put into the glass beaker and filled to 300 ml with de-ionized water. The prepared electrolyte was finally added to the Hull cell, where the pH value was adjusted. Finally, the filled electrolyte was mixed with gelatin hydrolysate.The experimental work was performed in the equipment shown in Figure 2.

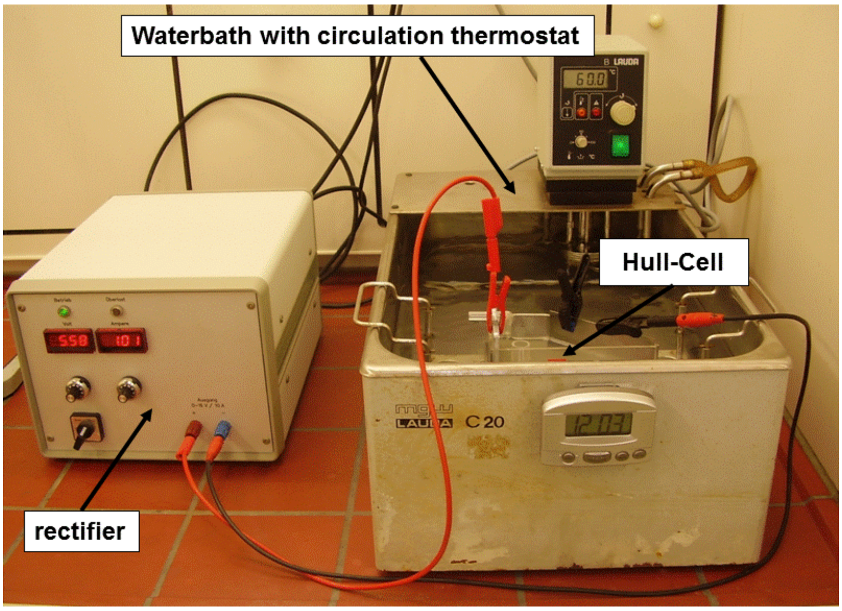


Figure 2 – Electroplating in the Hull cell
Рис. 2 – Гальванизация в ячейке Хулла
Slika 2 – Galvanizacija u Hulovoj ćeliji

The electroplating parameters in the Hull cell are shown in Table 2.

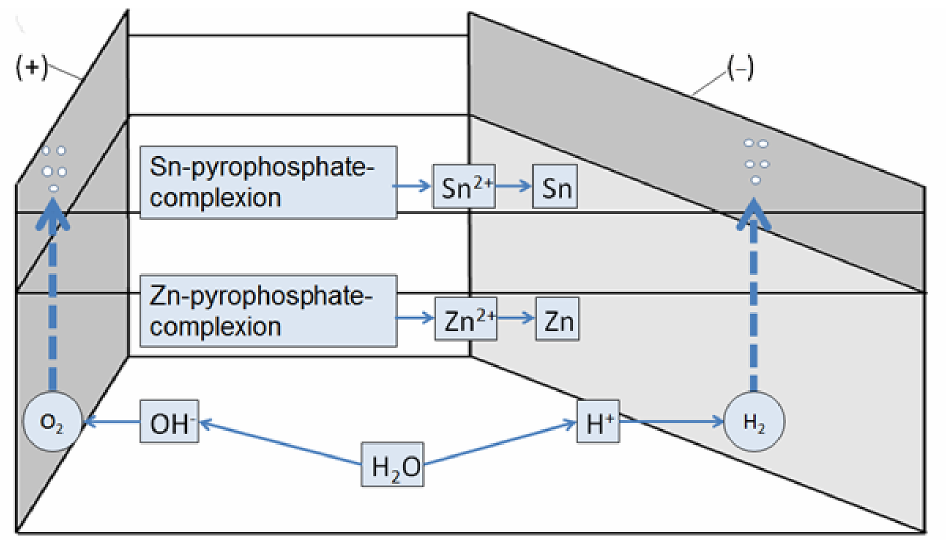
Table 2 – Electroplating parameters in the Hull cell
Таблица 2 – Параметры гальванического покрытия в ячейке Хулла
Tabela 2 – Parametri galvanizacije u Hulovoj ćeliji

Deposition conditions in the Hull cell	
Duration	20 min
Current strenght	1 A
pH-value	9.3
Additive	gelatine 1 g/l
Anode	stainless steel
Cathode	carbon steel
Flow conditions	without bath stirring

The characterization of layers was performed using the X-ray fluorescence analysis XRF, scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy EDXS. The X-ray fluorescence analysis was used for the determination of the thickness and the chemical composition of the prepared Zn-Sn layers. The measurements were performed using aFischerscope X-ray-XDL-device (Company Fischer, Germany). Before the measurement, a required calibration was done using the Fischer standards. The morphology of the deposits and the elemental composition was examined with a ZEISS DSM 982 Gemini scanning electron microscope with an EDX-System, Oxford.

Observations, results and discussion of the Sn-Zn electrodeposition in the Hull cell

During the experimental work, the gas formation was observed on both electrodes. The foam formation on the bath surface was observed during the electroplating process. The experimental design in the Hull cell with the simplified anode and cathode reactions is shown in Figure 3.



(–) Cathode (steel)

$Sn^{2+} + 2e^- \rightarrow Sn$

$Zn^{2+} + 2e^- \rightarrow Zn$

$2H^+ + 2e^- \rightarrow H_2$

(+) Anode (stainless steel)

$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$

Figure 3 – Schematic illustration of the anode and cathode reactions in the Hull cell
Рис. 3 – Схема реакций анода и катода в ячейке Хулла
Slika 3 – Šematski prikaz reakcija anode i katode u Hulovoj ćeliji

All coatings have a bright gray/silver appearance. The influence of the addition of gelatine was investigated, as well. In the absence of gelatine, a gray sponge-like layer was formed in the range of the studied current density (as shown in Figure 4).

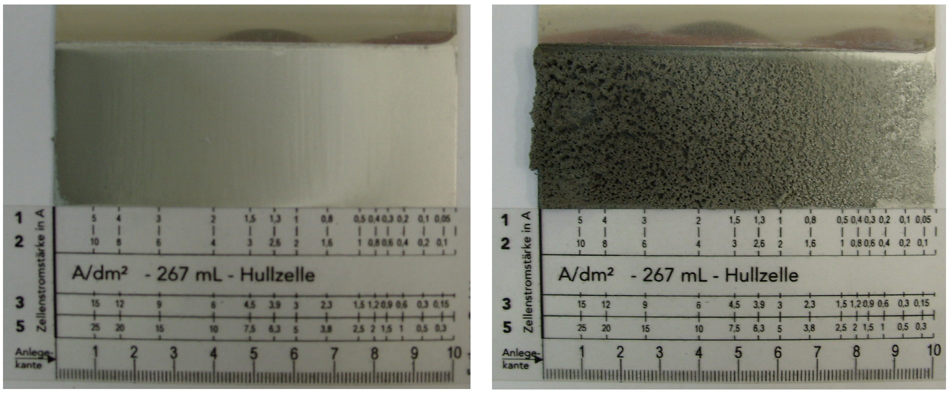


Figure 4 – Illustration of the Sn-Zn layer surface obtained from an electrolyte with 0.05 mol/l Zn; 0.05 mol/l Sn and 0.25 mol/l K4P2O7 at pH = 9.3 with 1 g/l gelatine (left) and in the absence of gelatine (right) (Working parameters: 1A; 60°C; 20 min.)

Рис. 4 – Поверхностный слой покрытия Sn-Zn, полученный из электролита при 0.05 mol/l Zn; 0.05 mol/l Sn и 0.25 mol/l K4P2O7 при значении pH = 9.3 с применением 1 g/l желатина (слева) и без применения желатина (справа) (рабочие параметры: 1А, 60°C; 20 мин.)

Slika 4 – Ilustracija površine sloja Sn-Zn dobijena iz elektrolita sa 0.05 mol/l Zn; 0.05 mol/l Sn i 0.25 mol/l K4P2O7 pri vrednosti pH = 9.3 sa1 g/l želatina (levo) i u odsustvu želatina (desno) (Radni parametri: 1A, 60°C; 20 min)

In Figure 5, a dependency of the chemical composition of the Sn-Zn layers on the electrolyte chemical compositionand the current density is presented. An increase in the current density and the zinc content in the bath led to a decrease of the Sn-content in the deposited Sn-Zn coatings in all cases.

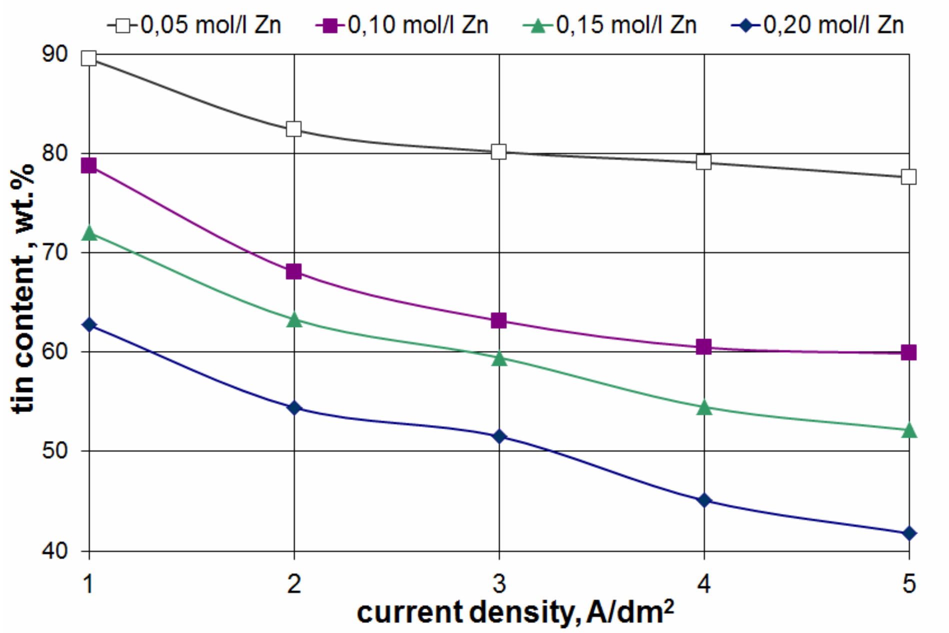


Figure 5 – Tin content in the Sn-Zn layers, depending on the zinc content in the bath and current density, at 60°C; pH = 9.3 with 0.05 mol/l Sn, c(P2O74-)/ c(Sn2+ + Zn2+)= 2.5 and 1 g/l gelatine; 1 A, 20 min.

Рис. 5 – Содержание олова в покрытии Sn-Zn, зависит от содержания цинка в ванной и плотности токана 60°C; при значении pH = 9.3 с 0.05 mol/l Sn, c(P2O74-) / c(Sn2+ + Zn2+)= 2.5 и 1g/l желатина; 1 A, 20 мин.

Slika 5 – Sadržaj kalaja u slojevima Sn-Zn, zavisno od sadržaja cinka u kupatilu i gustine struje na 60°C; pri vrednosti pH = 9.3 sa 0.05 mol/l Sn, c(P2O74-)/ c(Sn2+ + Zn2+)= 2.5 i 1g/l želatina; 1 A, 20 min.

For nearly all studied current densities, the electroplating at 40°C in comparison to that at 60°C led to a decreased content of tin in the layer (Figure 6). This is probably connected with a faster dissociation of the zinc pyrophosphate complex compared to that of the tin pyrophosphate complex, at higher temperature.

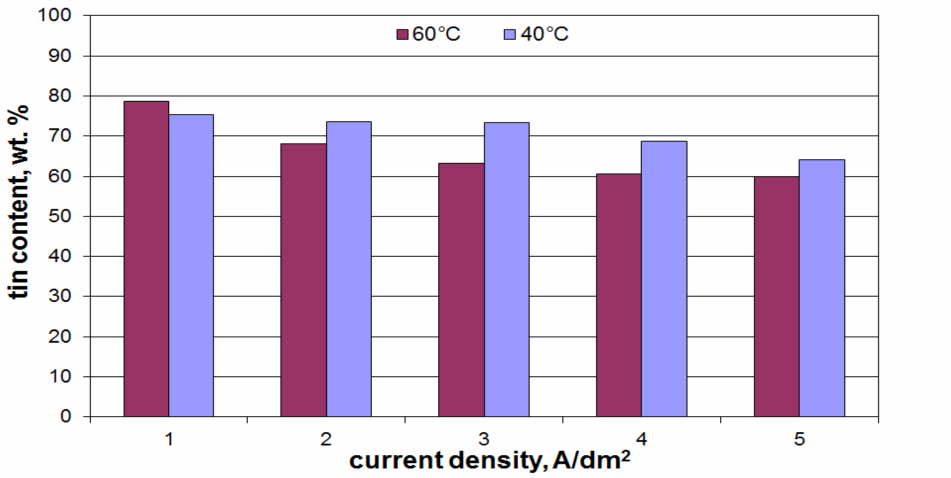


Figure 6 – Tin content in the Sn-Zn-layer depending on temperature and current density (electroplated from an electrolyte with 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 and 1 g/l gelatine; pH = 9.3; Hull cell: 1A; 20 min.)

Рис. 6 – Содержание олова в покрытии Sn-Zn, зависит от температуры и плотности тока (электрохимическое осаждение из электролита 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 с при применении 1g/l желатина; pH = 9.3; ячейка Хулла: 1 А, 20 мин.)

Slika *6* – Sadržaj kalaja u Sn-Zn sloju, zavisno od temperature i gustine struje (elektrohemijski nataloženo iz elektrolita sa 0.05mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 i 1 g/l želatina; pH = 9.3; Hulova ćelija: 1A; 20 min)

As shown in Figure 7, the deposited layer thickness and, consequently,the current efficiency increased with an increase in temperature from 40°C to 60°C. This behavior can be explained by an inhibition of diffusion of metal ions for discharging from the electrolyte inside the cathode, as well as by a greater reaction overvoltage at a lower temperature, which is caused through a slow dissociation of metal complexes. The increase in the current density led to a reduction in the cathodic current efficiency, which can be caused by the hydrogen favored deposition at higher current densities, probably provoked by the decrease of metal ions to be discharged at the cathode.

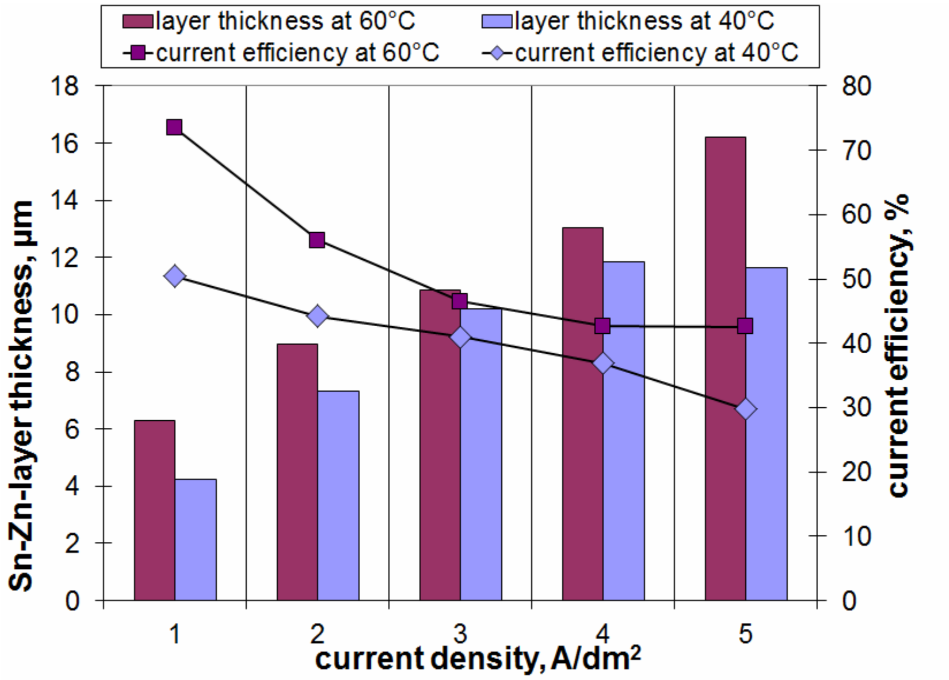


Figure 7 – Cathodic current efficiency and thickness of the Sn-Zn-layer depending on temperature and current density (electroplating from an electrolyte with 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 and 1 g/l gelatine; pH = 9.3; 1A; 20 min.)

Рис. 7 – Эффективность катодного тока и толщина Sn-Zn слоя покрытия зависят от температуры и плотности тока (электрохимическое осаждение из электролита 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 с при применении 1g/l желатина; pH = 9.3;1 A, 20 мин.)

Slika 7 – Efikasnost struje katode i debljina Sn-Zn sloja zavisno od temperature i gustine struje (elektrohemijsko taloženje iz elektrolita sa 0.05 mol/lSn; 0.1 mol/lZn; 0.375 mol/lK4P2O7 i1 g/l želatina; pH = 9.3; 1A; 20 min)

The EDXS analysis of the electrochemically deposited Sn-Zn-layers has confirmed the presence of both metals (Figure 8).

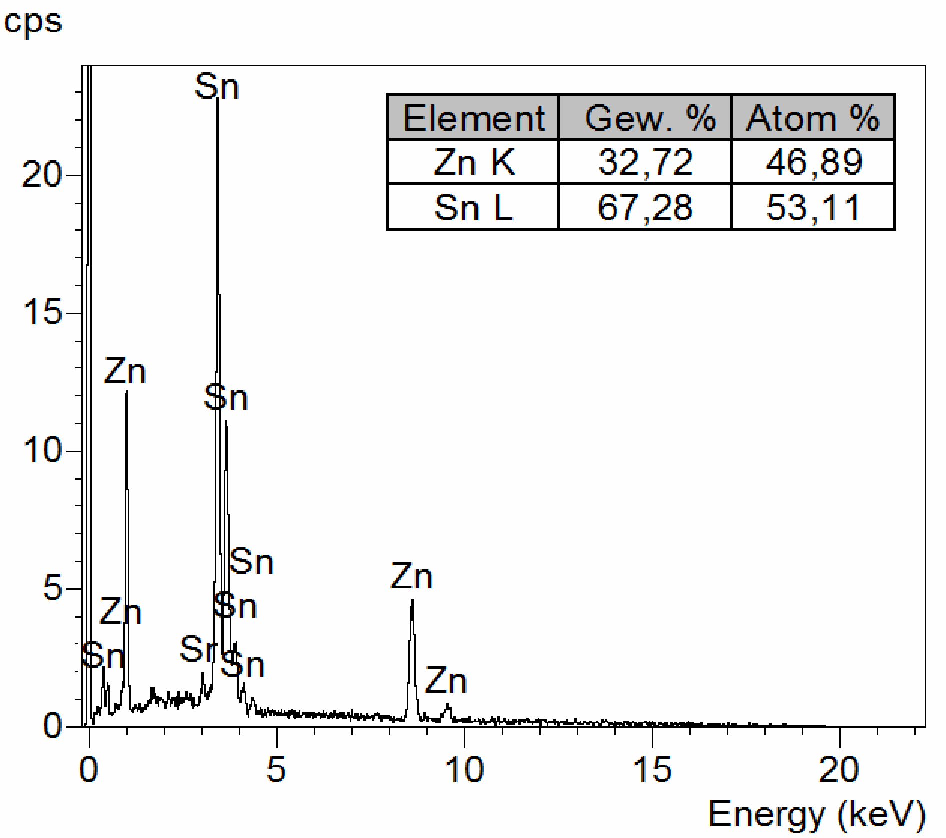
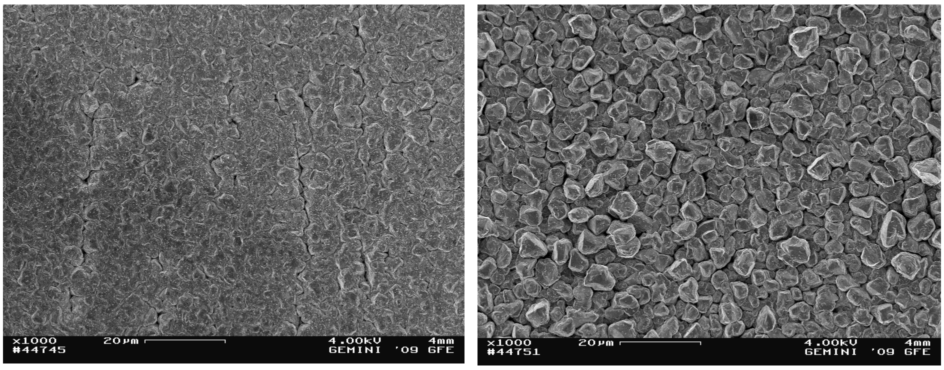


Figure 8 – EDX-spectrum of the Sn-Zn layer electrochemically deposited from an electrolyte with 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 and 1 g/l gelatine (60°C; pH = 9.3; 20 min) at 2 A/dm2

Рис. 8 – EDX спектр Sn-Zn слоев, осажденных при электрохимическом процессе из электролита с 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 и1 g/l желатина (60°C; pH=9.3; 20 мин.); pri 2 A/dm2

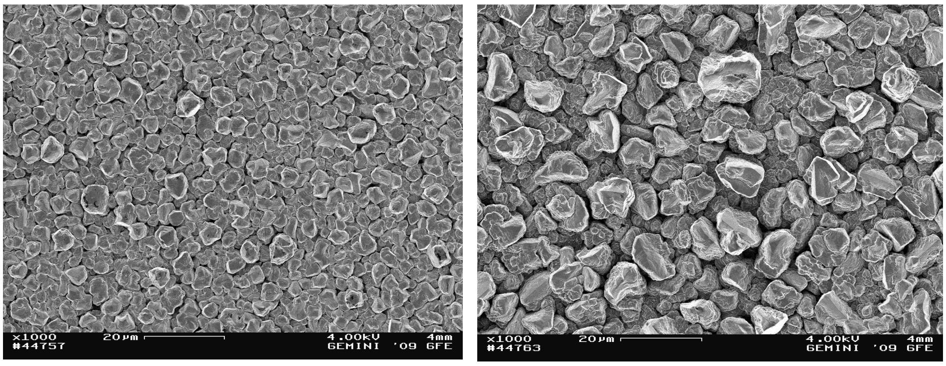
Slika 8 – EDX spektar Sn-Zn sloja nataloženog elektrohemijskim procesom iz elektrolita sa 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 i 1 g/l želatina (60°C; pH = 9.3; 20 min) pri 2 A/dm2

The SEM images of the Sn-Zn layers, deposited in two different baths at 2 A/dm^2 and 4 A/dm^2 are presented in Figure 9 and Figure 10. The SEM analysis of the Sn-Zn layers shows a fine-grained structure. An increase of the Zn-content in the layer led to the formation of a rough granular structure.



9 µm SnZn33-Layer / 2 A/dm^2 13 µm SnZn42- Layer / 4 A/dm^2

Figure 9 – SEM analysis of the Sn-Zn layers obtained from an electrolyte with 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 and 1 g/l gelatine (60°C; pH=9.3; 20 min.); magnification: 1.000 x
Рис. 9 – SEM анализ Sn-Zn слоев, полученных из электролита с 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 и 1 g/l желатина (60°C; pH=9.3; 20 мин.); масштаб увеличения: 1.000 x
Slika 9 – SEM analiza Sn-Zn slojeva dobijenih iz elektrolita sa 0.05 mol/l Sn; 0.1 mol/l Zn; 0.375 mol/l K4P2O7 i 1 g/l želatina (60°C; pH=9.3; 20 min.); uvećanje: 1.000 x



9 µm SnZn41-Layer / 2 A/dm^2 15 µm SnZn62-Layer / 4 A/dm^2

Figure 10 – SEM analysis of the Sn-Zn layers obtained from an electrolyte with 0.05 mol/l Sn; 0.2 mol/l Zn; 0.625 mol/l K4P2O7 and 1 g/l Gelatine (60°C; pH=9.3; 20 min); magnification: 1.000 x
Рис. 10 – SEM анализ Sn-Zn слоев, полученных из электролита с 0.05 mol/l Sn; 0.2 mol/l Zn; 0,625 mol/l K4P2O7 и 1 g/l желатина (60°C; pH=9.3; 20 мин.); масштаб увеличения: 1.000 x
Slika 10 – SEM analiza Sn-Zn slojeva dobijenih iz elektrolita sa 0.05mol/l Sn; 0.2 mol/l Zn; 0,625 mol/l K4P2O7 i 1 g/l želatina (60°C; pH=9.3; 20 min.); uvećanje: 1.000 x

A SnZn28layer was analyzed using the EDX analysis and a mapping function. Figure 11 shows a SEM image in gray. The element distribution images are shown in different colors: Zn-(red) and Sn-(green). The constituent parts are identified in the common layer in accordance wththeir ratios. The mixed elemental map shows that the layer is composed of a zinc layer located at the bottom and of many granules rich in tin. During the electrodeposition, zinc is preferentially deposited at the beginning, which is caused probably by an irregular co-deposition mechanism.

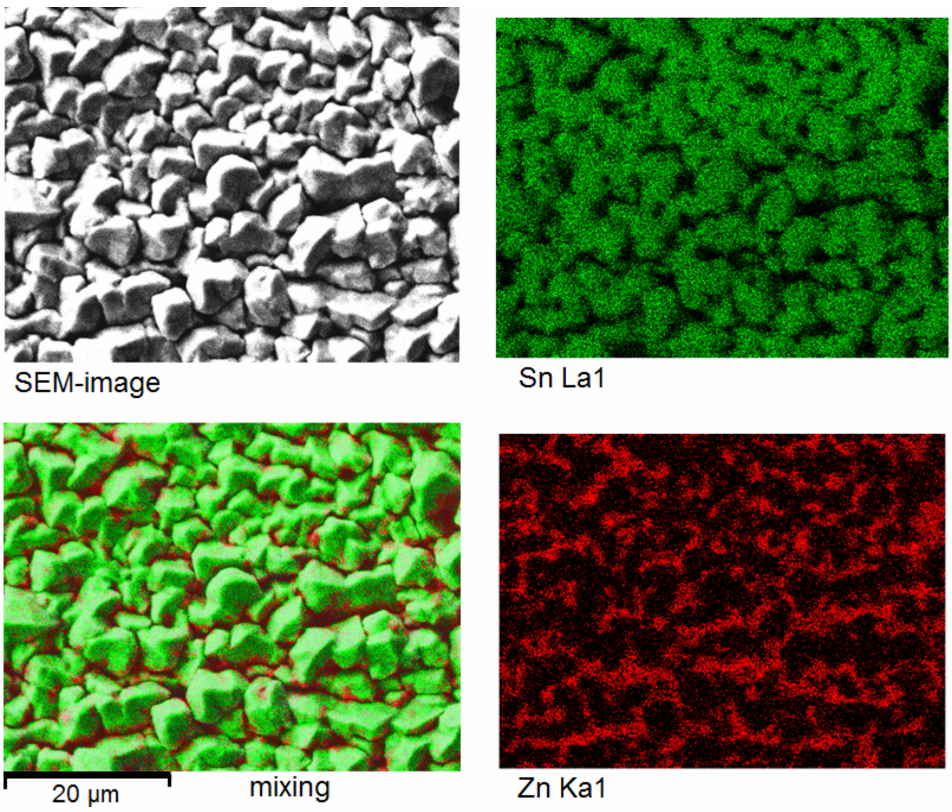


Figure 11 – SEM image and elemental maps in a SnZn28- layer (6 µm)
Рис. 11 – SEM изображение и карточка элементов одного слоя SnZn28 (6 µm)
Slika 11 – SEM fotografija i mape elemenata u jednom sloju SnZn28 (6 µm)

Electrochemical studies of the electrodeposition of Sn-Zn layers

The most important aim of the electrochemical investigations is a detailed analysis of different partial processes in order to arrange and understand them. The electrochemical behavior is studied using the following methods:

- Linear-Sweep-Voltammetry (LSV)
- Cyclovoltammogrammetry /CV)

Experimental setup for measurements

The experimental setup for the recording of the current-potential curves contains the following components (as shown in Figure 12):

- electrochemical three-electrode cell
- waterbath with thermostat
- potentiostat (typ: Iviumsoft)
- electronic dataacquisition

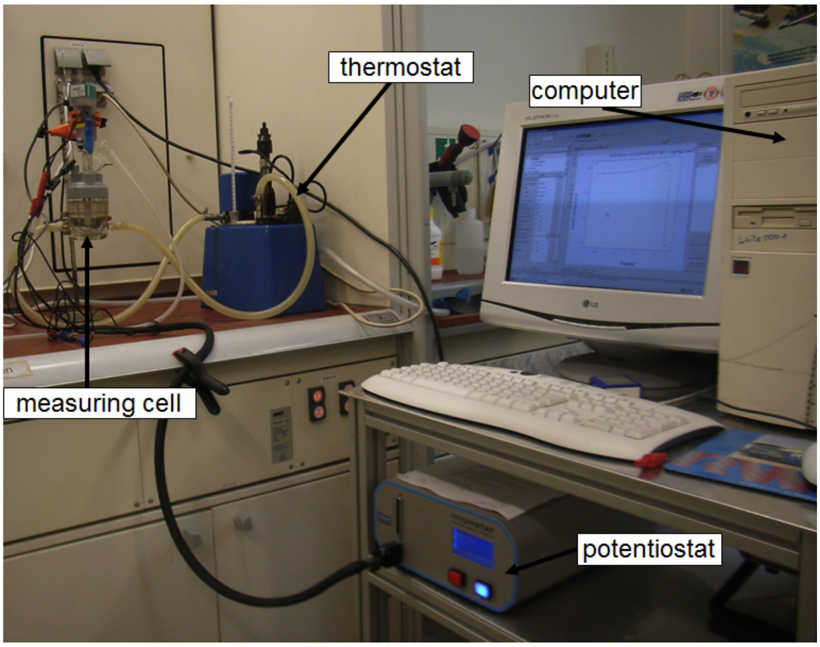


Figure 12 – Experimental setup for the electrochemical measurement
Рис. 12 – Экспериментальное оборудование для электрохимических измерений
Slika 12 – Eksperimentalna oprema za elektrohemijsko merenje

The electrochemical cell consists of a double walled glass beaker of 100 ml volume, connected with a waterbath and covered by a plastic lid. The five bore holes on the lid are required for the positioning of three electrodes, a thermometer and an injection tube for gas. The usedmeasuringcellisshown in Figure 13.

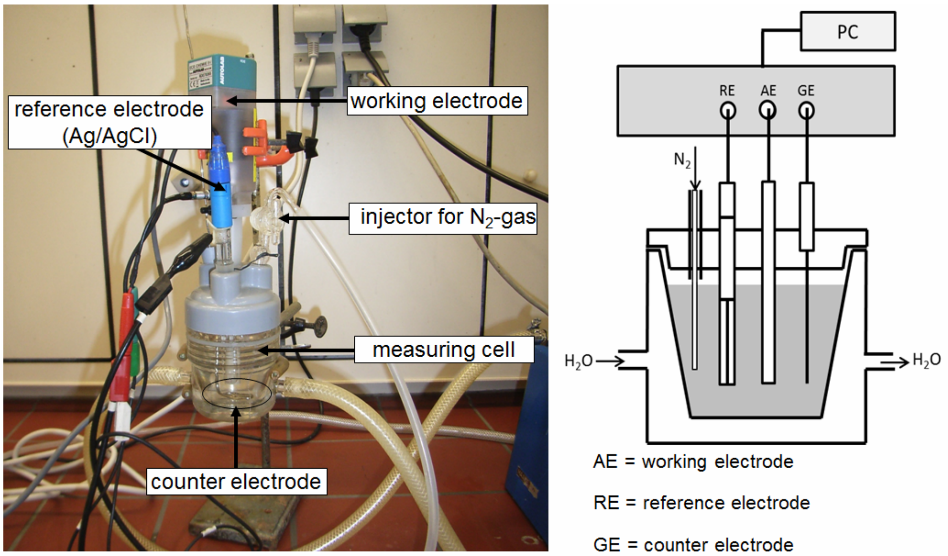


Figure 13 – Temperature-controlled 100 ml glass measuring cell with a three electrode setup
Рис. 13 – Стеклянная измерительная ячейка − 100 ml с контролируемой температурой и тремя электродами
Slika 13 – Staklena merna ćelija od 100 ml sa kontrolisanom temperaturom i povezane tri elektrode

In the voltammetric studies, a copper disc was used as a working electrode (surface area 0,785 cm^2). The working electrode potentials were referred to as an Ag/AgCl electrode. The counter electrode was a platinum rod.

The cathodic current- potential curves of tin, zinc, and tin-zinc deposition from a pyrophosphate electrolyte are shown in Figure 14. In the mixed Sn-Zn electrolyte, the deposition began at a more positive potential in comparison with the electrolytes containing only one metal.

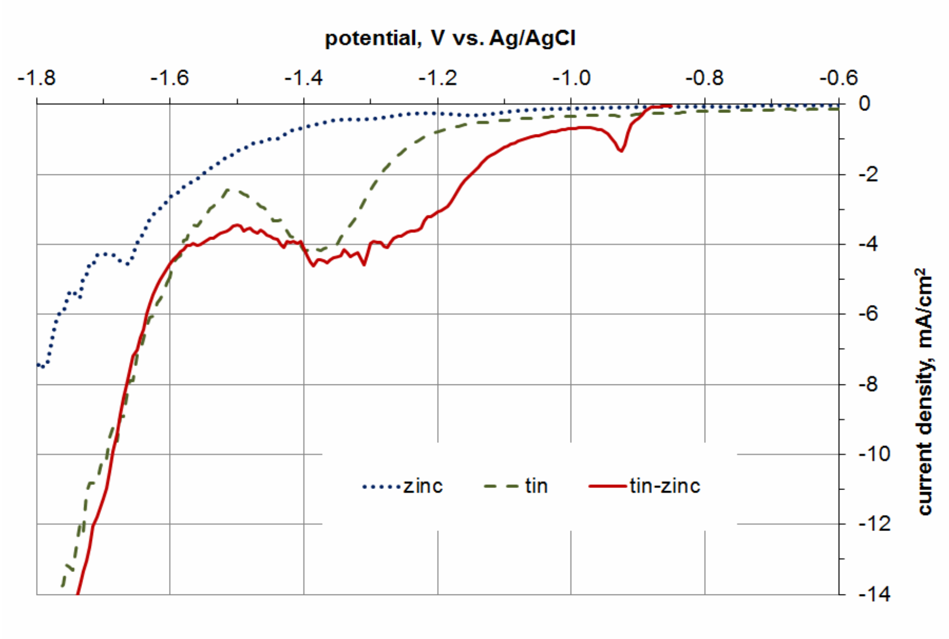


Figure 14 – Polarisation curves of tin, zinc- and tin-zinc deposition on copper at 60°C and pH = 9.3; v = 1 mV/s (0.05 mol/l Me + 0.25 mol/l K4P2O7 with 1 g/l gelatine)
Рис. 14 – Поляризационные кривые осажденного олова, цинка и сплава олово-цинк на меди при 60°С, со значением pH = 9.3; v = 1 mV/s (0.05 mol/l Me + 0.25 mol/l K4P2O7 с применением 1 g/l желатина
Slika 14 – Polarizacione krive nataloženog kalaja, cinka i legure kalaja i cinka na bakru na 60°C pri vrednosti pH = 9.3; v = 1 mV/s (0.05 mol/l Me + 0.25 mol/l K4P2O7 sa 1 g/l želatina

The cyclovoltammetry allows a determination of electrode kinetics in a wide potential range using only one measurement. All measurements were performed at a scan rate of 5 mV/s, scanning towards negative potentials. In Figure 15, the cyclic voltammograms obtained from pyrophosphate electrolytes are given. After comparing the single diagrams for pure zinc, pure tin and the Sn-Zn alloy, it can be concluded that, in the case of a co-deposition, the reduction peaks for both alloying elements were shifted about 100 mV to the positive potential value in comparison to the single deposition. This indicates that, in a mixed electrolyte, a strong interdependency happens between the adsorbed zinc and tin species.

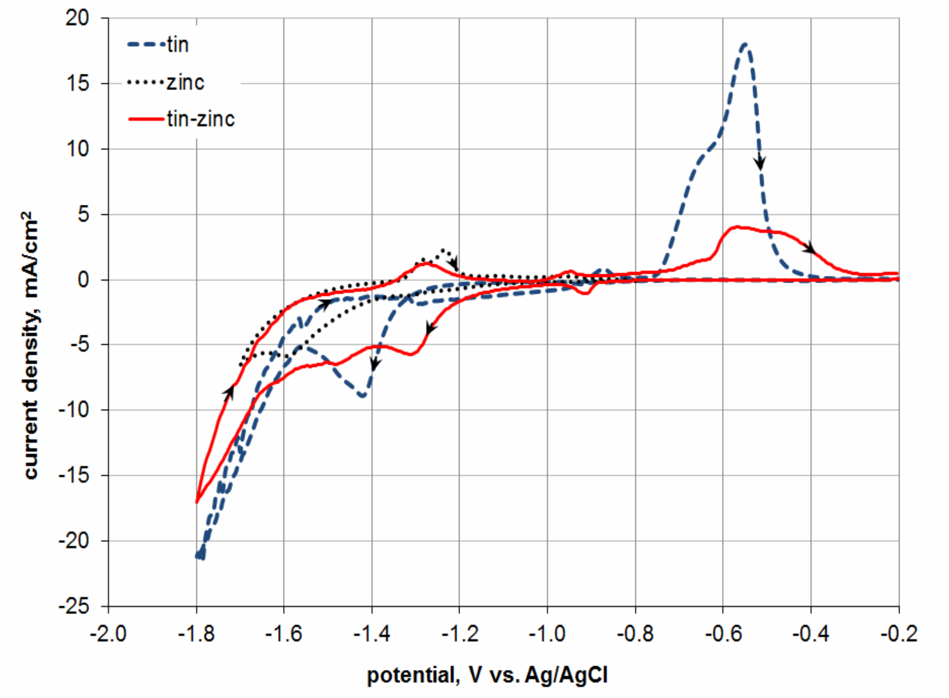


Figure 15 – Cyclic voltammogramms of zinc-, tin and tin-zinc electrodeposition in a pyrophosphate electrolyte with 0.05 mol/l Zn or/and 0.05 mol/l Sn, 0.25 mol/l K4P2O7 and 1g/l gelatine at 60°C and pH=9.3; AE: copper; v = 5 mV/s.
The arrows indicate the scan direction.

Рис. 15 – Циклическая вольтамперограмма электрохимических осаждений цинка, олова и сплава цинк-олово в пирофосфатном электролиту с 0.05 mol/l Zn и/или 0.05 mol/l Sn, 0.25 mol/l K4P2O7 и 1g/l желатина при 60°C и pH=9.3; AE: медь;
v = 5 mV/s. Стрелка обозначает направление сканирования.

Slika 15 – Ciklični voltamogrami elektrohemijski nataloženog cinka, kalaja i legure cinka i kalaja u pirofosfatnom elektrolitu su 0.05 mol/l Zn i/ili 0.05 mol/l Sn, 0.25 mol/l K4P2O7 i 1g/l želatinana 60°C i pH=9.3; AE: bakar; v = 5 mV/s.
Strelica označava pravac skeniranja.

Electrochemical behavior of the Sn-Zn layers in 3 wt.%NaCl

The corrosion behavior of the Sn-Zn layers with different chemical compositions was studied by means of potentiodynamic polarization tests (Wang, Pickering, &Weil, 2004, pp.34-37). An evaluation of the corrosion parameters with the aid of the Tafel extrapolation method has shown that all investigated Sn-Zn layers can be utilized for the protection of steel substrate in chloride-containing media as a sacrificial anode (Taguchi, Bento &Mascaro, 2008, pp.727-733)

Between the three Sn-Zn layers, the layer with 28.5 wt. % zinc has exhibited the lowest corrosion rate (Table 3).

Table 3 – Comparison of the corrosion parameters of Sn-Zn layers obtained from different pyrophosphate baths (corrosion medium: 3 wt. % NaCl solution at room temperature)
Таблица 3 – Сравнение коррозийных параметров покрытия из сплавов цинка и олова, полученных из различных пирофосфатных ванн (коррозийная среда: 3 вес % раствор NaCl при комнатной температуре)
Tabela 3 – Poređenje korozivnih parametara slojeva legure cinka i kalaja dobijenih iz različitih pirofosfatnih kupatila (korozivna sredina: 3 tež% rastvor NaCl na sobnoj temperaturi)

	Steel	SnZn 13.5%	SnZn 28,5%	SnZn 48%
corrosion potential, V_{SCE}	-0.781	-1.159	-1.137	-1.18
corrosion current density, A/cm^2	4.92E-07	2.92E-06	2.35E-06	5.43E-06

Conclusions

This work studied the electrodeposition of Sn-Zn layers from a weak alkaline sulphate-pyrophoshate electrolyte. The deposition of the layers was performed in the Hull cell. The electrochemical characterization was performed in a measuring cell with a three electrode setup employing Linear-Sweep-Voltammetry (LSV) und Cyclovoltammetry (CV). The corrosion behavior of the deposited Sn-Zn-layers was investigated using the potentiodynamic method in order to determine the current-potential curves.

The most important findings are presented below:

• During electroplating, a gas formation was observed on both electrodes. All coatings had a gray/silver bright look with a fine striation.

• The chemical composition of deposits varied depending on different bath compositions and current densities.

• An increase in current density and zinc content in the bath increased the content of zinc in the deposited Sn-Zn layer. For example, an increase in current density from 1 A/dm^2 to 5 A/dm^2 at the same chemical composition of the bath led to an increase of about 20 wt. % of zinc in the layer. At the same current density, an increase of tin content from 30 to 65 wt. % in the bath led again to an increase of tin content of about 35 wt % in the layer.

• An increase of current density led to a decrease of current efficiency at all studied bath compositions.

• The SEM analysis of the Sn-Zn layers showed a dense, fine-grained structure. An increase of the zinc content influenced the formation of a rough crystalline arrangement.

• In the absence of gelatin-hydrolysate, the sponged structure was formed, which confirms that the limited current density was overpassed. An addition of colloid admixture led to a formation of smooth layers.

• In the mixed Sn-Zn electrolyte, the deposition began at the more positive potential in comparison to that for each single metal, which means that a strict interdependence exists between absorbed tin and zinc species. An increase of zinc in the bath led to a replacement of the deposition curves again to the negative values of potential.

• The obtained results of electrochemical investigations reveal that the corrosion potential of all studied Sn-Zn alloys was more negative than the one for the steel sample. Therefore, it is possible to use all three investigated tin-zinc alloys as an anode for protection of steel substrate in a chloride medium.

At the end of this conclusion, it might be pointed out that Sn-Zn-layers with good corrosion characteristics can be deposited from a sulfate-pyrophosphate bath (Stopic, 2015, pp.101). Using different characterization techniques (Hull cell, RFA-, SEM- and EDX-analysis, Linearsweep- und Cyclovoltammetry) enables a complete study of very important parameters and their interdependency (Dubent, et al. 2007, pp.146-152).

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ЭЛЕКТРОХИМИЧЕСКИЕ ОСАЖДЕНИЯ, КЛАССИФИКАЦИЯ И ИСПЫТАНИЯ КОРРОЗИИ ПОКРЫТИЯ НА ОСНОВЕ ЦИНКА И ОЛОВА, ОБРАЗОВАННОЙ НА ПОВЕРХНОСТИ ПИРОФОСФАТНОЙ ВАННЫ

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ОБЛАСТЬ: химические технологии, электрохимия, коррозия
ВИДСТАТЬИ: оригинальная научная статья
ЯЗЫКСТАТЬИ: английский

Резюме:

Покрытия из олова и цинка являются потенциальным аналогом токсичного кадмия для антикоррозийной защиты.

Покрытия на основе сплава олово-цинк являются отличной антикоррозийной защитой для стальных изделий. При осаждениев качестве барьерного слоя используется олово, а в качестве гальванического защитного слоя–цинк.

Покрытия на основе олово-цинк первоначально применялись для защиты шасси электрооборудования и электронной техники, а также для защиты критических автодеталей, например,тормозной системы.

В данной работе приведены результаты успешного применения сплава на основе олово-цинк в качестве покрытия пирофосфатных ванн.

Соответствующие пропорции сплава олова и цинка определены составом ванны и операционных параметров нанесения каждого отдельного слоя покрытия. Для электрохимических испытаний применялась ячейка из трех электродов.

Испытания механизма электрохимического осаждения Sn-Zn покрытия проводились линейной и циклической вольтаммограммой. Параметры коррозии, включая влияние потенциал-время, коррозийный потенциал и плотность тока коррозии электрохимические осаждения сплава олово-цинк различного состава тестировались в растворе с содержанием 3% NaCl.

Коррозийная стойкость зависит от состава отдельных слоев. Слой, содержащий Sn-28Zn отличается лучшими антикоррозийными свойствами.

Ключевые слова: *электрохимическое осаждение, коррозия, гальванические покрытия, цинк, олово.*

ELEKTROHEMIJSKO TALOŽENJE, KARAKTERIZACIJA I ISPITIVANJA KOROZIJE SLOJEVA NA BAZI CINKA I KALAJA NASTALIH TALOŽENJEM IZ PIROFOSFATNIH KUPATILA

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OBLAST: hemijske tehnologije, elektrohemija, korozija
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Sažetak:

Slojevi kalaja i cinka označeni su kao potencijalna alternativa za otrovni kadmijum korišćen kao zaštitni korozivni sloj. Slojevi na bazi legure kalaj-cinka poseduju izuzetnu korozivnu zaštitu za čelik, kombinujući zaštitu korišćenog kalaja kao barijere zajedno sa galvanskom zaštitom od cinka. Prevlake na bazi kalaja i cinka prvobitno su korišćene za šasije električnih i elektronskih aparatura ili za kritične delove i kočione sisteme. U ovom radu legure na bazi kalaja i cinka uspešno su proizvedene iz baznih pirofosfatnih kupatila. Proces izdvajanja metala daje kompaktan i finozrnasti deposit. Željeni odnosi cinka i kalaja u nanesenoj leguri odredjeni su od sastava kupatila i operacionih parametara tokom izdvajanja slojeva. Sistem od tri elektrode korišćen je za elektrohemijska istraživanja. Mehanizam elektrohemijskog taloženja Sn-Zn sloja ispitivan je linearnom i cikličnom voltametrijom. Parametri korozije, uključujući zavisnosti potencijal–vreme, korozivni potencijal i gustinu struje korozije elektrohemijski taložene kalaj-cink legure različitih sastava izvođeni su u rastvoru koji sadrži 3% NaCl. Korozivna otpornost zavisi od sastava izdvojenog sloja, a sloj koji sadrži Sn-28 Zn pokazao je najbolja antikorozivna svojstva.

Ključne reči: *elektrohemijsko taloženje, korozija, galvanski slojevi, cink, kalaj.*

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DOUBLE ELECTRICAL LAYER IN THE CATHODE SPOT

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ARTICLE TYPE: Original Scientific Paper
ARTICLE LANGUAGE: English

Abstract:

The paper describes a new phenomenon of the generation of the double electrical layer above the cathode spot surface. The neutralization of this layer leads to the reverse current of free electrons, generated due to negative ions ionization. The negatively charged flame of the cathode spot periodically ignites and attenuates, so the duration of the cathode spot existence is defined by this oscillating process. The reverse motion of the cathode spot in the longitudinal magnetic field takes place owing to the generation of the reverse high-power neutralization current of the double electrical layer by the electrons appearing during the negative ions ionization in the cathode flame.

Key words: *electric discharge, cathode spot, cathode flame, negative ions, double electrical layer.*

Introduction

The vacuum plasma coatings technique is widely used for constructional materials hardening and friction force decreasing (Baldaev, Borisov, Vachalkin, 2007), (Mrochek, Vershina, Ivashchenko, et al, 2004), (Grigoryants, 1989). The ion plasma technique is mainly applied for the vacuum plasma coatings deposition. In this case, the vacuum arc burns in the plasma material of the cold cathode due to its discharge current sputtering. This technique is quite complicated to be applied as it is difficult to determine the processes taking place inside the cathode spot and which plasma composition can occur in the cathode flames of the arc discharge.

The processes occurring inside the cathode spot were studied in detail by (Kesaev, 1968). As a result, the fundamental characteristics of the cathode spots were determined as well as the main directions of further investigations. The spectroscopic investigations of the cathode spots and the explosive processes occurring in the cathode flames were specially investigated by Kesaev. He investigated in detail the effect found by Shtark in 1903, where the cathode flames in the tangential magnetic field are not deflected in accordance with Ampere's law (even nowadays this effect has no convincing explanation).

The problems raised by Kesaev are solved to a certain extent, but not completely. The spectroscopic investigations of the cathode flames of the arc and sparkle discharges were carried out by Gretchikhin together with colleagues in the middle of the 1960s and it is shown that the plasma generation in the cathode flames is determined by the presence of negative ions inside the flames (Gretchikhin, Tyunina, 1967), (Gretchikhin, Davydov, Minko, Ya, 1968), (Gretchikhin, 1974).

The explosive processes investigations in the cathode flames were carried out by Mesyats with colleagues and it was found that micro explosions can be generated inside the cathode spots on separated low-sized particles, called ectons, (Mesyats, 2000), (Mesyats, 1993), (Mesyats, 1995).

During the vacuum plasma technique development, some new problems appeared, such as: 1 – why there is the presence of the liquid phase under micro explosions in the cathode spot; 2 – what processes determine the electron energy distribution, and, consequently, why the percentage ratio of the ions with a different degree of ionization does not correspond to Saha equation; 3 – why the cathode flames under the longitudinal magnetic field application do not deflect in accordance with Ampere's law, etc. In this regard, there is a goal to develop the model of erosion plasma generation which could quite convincingly describe the character of the plasma generation in the high-current vacuum arc. So, the following actions should be taken to solve the given tasks:

- to develop the exact model of the micro explosion in the cathode spot with regard to negative ions generation;
- to study the effect considering the cathode spot heating and liquid phase generating;
- to find out the processes leading to the electronic component plasma heating and to prove the percentage ions composition in the cathode flame in accordance with experimental data; and

- to find the cause of the reverse motion of the cathode flame in the longitudinal magnetic field.

Therefore, we consistently considered all the raised issues as applied to the erosion plasma of the cathode spots.

Negative ions in the explosive processes

Only the external atoms of the separate cathode material cluster are in contact with surrounding atoms during an explosion in the cathode spot. Cluster ionization energy is lower than 2 eV (Gretchikhin, 2008), while the energy of the electron affinity of an atom is slightly lower (Messi, 1979). Under the melting point, due to the tunnel-effect, the valence electrons of the surrounding atoms and clusters transverse to the atoms of the explosive cluster. The cluster is split onto separate free atoms in the moment of explosion. The built-in dipole electrical moments of the free atoms in the electric field of the cathode potential drop are lined in the field so the positive charge is in contact with the cathode material surface. The energetic scheme of the cluster atom interaction with the cathode surface is shown in Fig.1. The probability of this is determined by the transparency ratio of the potential barrier during the tunnel-effect:

$$W = \frac{n_a^-}{n_a} = \exp\left[-\frac{4\pi d}{h}\sqrt{2m_e(E_1 - E_2)}\right], \quad (1)$$

where $d = r_a - r_k$ –difference between the atom radius and its covalent radius; E_1 – cluster energy ionization of the cathode material; E_2 – energy of the electron affinity of an atom; m_e – electron mass.

As an example, the following cathode materials can be examined: iron, titanium, and copper[1].

Not all of the cluster atoms of the surface layer are directly in contact with atoms and clusters of the surroundings. Taking this into consideration, the general probability of the fact that titanium atoms leave the cathode spot by means of negative ions is:

$$W_{gen.} = \frac{N_{cl.} - \Delta N_{cl}}{N_{cl.}} W \ . \quad (2)$$

Here $N_{cl.}$ – general number of particles in the cluster and ΔN_{cl} – number of particles of the surface layer which are not in direct contact with surrounding atoms of the cathode material.

[1] The choice of these materials is explained by the difference in the crystal structure.

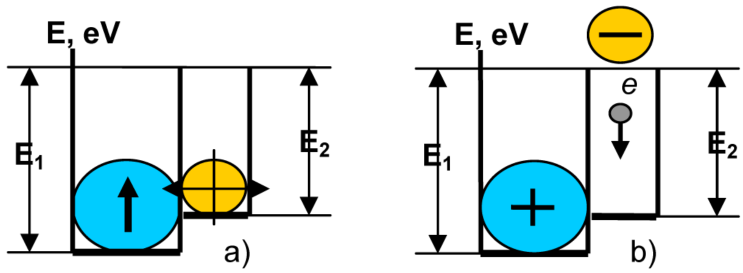

Figure 1 – Scheme of the negative ions generation in the cluster explosion process: a) – model of the cluster atoms interaction with the substrate and b) – model of the electrical charge separation during vapor ejection after a cluster explosion
Рис. 1 – Схема образования отрицательных ионов в процессе взрыва кластера: а) – модель взаимодействия атомов кластера с основой и б) – модель разделения электрических зарядов при выбросе пара после взрыва кластера
Slika 1 – Šema obrazovanja negativnih jona tokom procesa eksplozije klastera a) – model interakcije atoma klastera sa substratom i b) – model separacije naelektrisanja tokom izbacivanja pare nakon eksplozije klastera

For example, iron clusters have the bcc structure, where there are 9 diatomic molecules, out of which only 4 molecules are in contact with the cathode material. The cluster radius is $r_{cl.}$ = 3.78 Å, the cluster ionization potential - $E_1 = 1.46$ eV (Gretchikhin, 2008), the negative ion potential – $E_2 = 0.163$ eV, and the difference between the atom radius and the covalent radius is – $d = r_a - r_k = 0.455$ Å. On the basis of these data, the concentration of negative iron ions in the cathode flame of the vacuum arc is $W_{gen.}$ ~ 0.261

Titanium clusters have the fcc close-packed structure, where only 9 from 13 triatomic molecules are directly in contact with the surroundings. So only these 9 molecules are negative ions, and the cluster radius is $r_{cl.}$ = 4.38 Å, the cluster ionization potential - $E_1 = 1.53$ eV, th e negative ion potential – $E_2 = 0.079$ eV and $W_{gen} \approx 0.115$.

Copper clusters have the fcc structure, where there are 13 triatomic molecules, out of which only 8 molecules are in contact with particles from the surroundings. The cluster radius is $r_{cl.}$ = 3.84 Å, the cluster ionization potential - $E_1 = 1.633$ eV (Gretchikhin, 2008), the negative ion potential – $E_2 = 1.228$ eV, and the difference between the atom radius and the covalent radius – $d = r_a - r_k = 0.482$ Å. On the basis of these data, the concentration of negative copper ions in the cathode flame of the vacuum arc is $W_{gen.}$~ 0.150

The passage of discharge current of the cluster length, i.e. its diameter is:

$$\tau = 2r_{cl.} / v = 2 \cdot r_{cl.} \cdot \sqrt{\varepsilon_r} / c \text{, sec.} \tag{3}$$

Here $r_{cl.}$ – the minimum radius with a separate emissive cell in the cathode spot i.e. the cluster radius, c – speed of light in vacuum, and ε_r - relative dielectric medium permeability.

The electric polarization theory for metals was developed by (Gretchikhin, Physics, 2008) and the calculations were made for the relative permeability for natrium, aluminum, iron and copper, while the relative dielectric permeability for titanium was calculated separately and was $\varepsilon_r \sim 3.965 \cdot 10^{13}$. On the basis of (3), the passing time of the electromagnetic wave through the cluster is τ - $1.085 \cdot 10^{-11}$ sec for iron, $\tau = 1.84 \cdot 10^{-11}$ sec for titanium and $\tau = 5.51 \cdot 10^{-11}$ sec for copper.

This time is necessary for the cluster to absorb discharged current energy. Since the process time is ~ $(1 \div 5) \cdot 10^{-11}$ sec, the cluster destruction process has an explosive behavior. The pressure, emerging at the cluster explosion moment, can be calculated by the formula:

$$P_{\max.} = \frac{N_{cl.}}{(2 \cdot r_{cl.})^3} k_B T_{boil.} . \tag{4}$$

Here $N_{cl.}$ – number of cluster particles multiplied by the number of atoms in the particle. Considering the overall atoms number in the cluster, the pressure at the cluster explosion inside the cathode spot is $1.82 \cdot 10^9$ Pa for iron, $1.98 \cdot 10^9$ Pa for titanium and $3.35 \cdot 10^9$ Pa for copper. Such pressure values can occur during the explosive blast (Gretchikhin, Rubleva, 2006), (Litvinskiy, 2006).

During the cluster explosion, a number of negatively charged particles are emitted from the cathode spot[2]. In this case, the electric current density of the charge separation during the flame discharge in the cluster explosion with double electrical layer generation is:

$$j_k = \frac{N_{cl} W_{gen} e}{V_{cl}} v_f , \tag{5}$$

where $V_{cl.}$ – the cluster volume and v_f - the flame emission rate from the cathode spot and it is determined by using the point explosion model.

[2] The attention was paid to this effect in the late 19th and at the beginning of 20th century (Kesaev, 1968).

The shock wave rate in solids for the point explosion is determined by the formula (Korobeinikov V. P., Melnikova N.S., Ryazanov E.V. 1961) and (Kostenboim X.S. 1974)

$$v_{sh.w.} = \frac{2}{5}\left(\frac{E_0}{\alpha' \rho_c}\right)^{1/2} \frac{1}{r_{cl.}^{3/2}}, \tag{6}$$

where $\alpha' \approx 0.851$, E_0 - energy emitted in the cluster during the current discharge flow and ρ_c – the cathode material density.

The energy emitted in the cluster is:

$$W_k = L_{\max} \frac{\pi d_k^2}{4} \tau, \text{ J}, \tag{7}$$

where L_{max} – the Poynting vector, d_K – the cathode spot size and τ - the electromagnetic wave passage time through the cathode material cluster.

On the basis of the cathode spot "autographs", it is shown in this work (Kesaev I.G. 1968) that the cathode spot diameter is increased due to arc current and film thickness. When the arc current and films thickness are quite small, the ratio of the discharge current to the "autograph" width is sufficiently small, and it is stabilized with a current and film thickness increase. When the arc current and films thickness are high, the ratio of the discharge current to the "autograph" width increases quickly. In the first case, not all the discharge current power is used for the film evaporation, while under the high currents and film thicknesses the spot size significantly enlargers due to "autographs" edges melting. Taking this into consideration, the probable "autograph" size of the separate copper cathode spot is $(1 \div 2) \cdot 10^{-5}$ m (the average value for further evaluations is $d_k = 1.5 \cdot 10^{-5}$ m[3]).

The cathode spot is only influenced by the arc discharge current, so the average current density is - $J_k = 4I / \pi d_k^2$.

In this case, the Poynting vector is defined by the Joule law

$$L_{\max} = J_k U_k, \tag{8}$$

where U_k – a near-cathodic potential drop. The average values of the near-cathodic potential drop are listed here (Kesaev, 1968) and it is quite

[3] Since the magnetic pressure of the current discharge is equal to the gas-kinetic pressure in the cathode flame, then the pressure in the cathode flame at this spot diameter ~ $9.0 \cdot 10^5$ Pa. Such a quick pressure drop in the cathode flame while exiting the cathode spot is caused by the discharge-like "vacuum expansion".

convincingly shown that this potential drop coincides with first atoms ionization potential of the cathode materials for most metals.

As a result, the flame discharge rate of the cathode flame can be calculated by means of the point explosion model and it is 4324 m/s for iron, 4652 m/s for titanium and 7820 m/s for the copper cathode. During cathode processes modeling of the pulsed discharge by laser, the flame discharge rate at some distance from the surface turned out to be 3900 m/s (Gretchikhin, Minko, 1967), while in the vacuum arc – 12.5 km/s under an arc current of 115 A (Kesaev, 1968). The flame discharge rate was 8.8 km/s for the iron cathode under an arc current of 142 A (Kesaev, 1968), while these investigations were not carried out for the titanium cathode. 1968). The found values are quite reliable and they can be used in further calculations. Then the current density, caused by the negative ions discharge from the cathode spots is ~ $4.6 \cdot 10^{12}$ A/m^2 for the titanium cathode spot, ~ $1.37 \cdot 10^{13}$ A/m^2 for iron and ~ $1.3 \cdot 10^{13}$ A/m^2 for copper. Exactly the same current densities were experimentally found during the ecton explosion (cluster) (Mesyats, 2000), (Mesyats, 1993) and (Mesyats, 1995).

The energy to be transferred to the cluster to disintegrate it into separate atoms is:

$$\Delta Q = \frac{m_{cl.}}{\mu} \Delta H_{boil} \,, \tag{9}$$

where m_{cl} - the cluster mass, μ - the cathode material molar mass $\Delta H_{boil.}$ - the sublimation heat. This energy is 1.75 eV for the iron cluster, 3.46 eV for the titanium one and 1.92 eV for the copper one. Using these values of energy, it is possible to determine the maximum current density which leads to the complete cluster disintegration into separate atoms by the formula:

$$j_{\max.} = \frac{\Delta Q}{U_k S_k \tau_k} \,. \tag{10}$$

Here U_k, S_k and τ_k - the cathode potential drop, the cluster area and the passage time of the cluster length by the discharge current, respectively. The near-cathodic potential drops are listed here (Kesaev, 1968) and (Kolesnik, Kolesnik, 2009), while the cluster radius values are given in (Gretchikhin, 2008). The passage time is determined by the rate of the electromagnetic waves in the cathode material and is equal to $\tau_k = 2r_{cl.}\sqrt{\varepsilon_r}/c$ (ε_r - relative dielectric permeability of the cathode material and c - the speed of light). The limit current density leading to the complete cluster destruction is respectively $1.4 \cdot 10^9$ A/m^2 for the iron cluster, $2.3 \cdot 10^9$ A/m^2 for titanium and $4.7 \cdot 10^8$ A/m^2 for copper. Therefore, the current density emerging during the cathode cluster explosion in the vacuum arc is significantly higher than the current density of complete cluster destruction. The average current density on the cathode spot is about ~ 10^{12} A/m^2 when the discharge current is 100 A. The clusters of almost all cathode materials explode and disintegrate into separate atoms under this current density and they are discharged as a vapor-gas phase from the cathode spot.

The electric current is generated by every cluster explosion – $I_k = j_k S_k$, and the number of clusters to be exploded simultaneously in the cathode spot is – $n_k = I / I_k = I / j_k S_k$. When the current discharge is 100 A, the total number of clusters is $n_k = 2.86 \cdot 10^7$ for the titanium cathode, $n_k = 1.63 \cdot 10^7$ for iron and $n_k = 1.32 \cdot 10^7$ for copper. When the cathode spot diameter is 10^{-5} m, the total number of clusters is $n_{k,n} = 1.3 \cdot 10^8$ for the titanium cathode, $n_{k,n} = 1.75 \cdot 10^8$ for iron and $n_{k,n} = 1.7 \cdot 10^8$ for copper. It should be no more than 5 erosion cells for the titanium cathode, no more than 10 for the iron cathode and no more than 12 for the copper cathode under a current discharge of 100 A (Kolesnik, Kolesnik, 2009). It was found that the number of erosion cells in the cathode spot was within 4-12, depending on the discharge conditions. This is confirmed by estimations on the basis of negative ions emission.

The electric current is generated by every exploded cluster, and all these currents produce the emission cell with public electric current which is equal to the current discharge to that fact. Owing to this, parallel currents are integrated by the Ampere force, and this effect is called current discharge pinching.

During the clusters explosion, the electric current is conducted by negative ions, but not free electrons. The magnitude of the pulse current during every separate cluster explosion corresponds to experimental data, found by (Mesyats, 2000), (Mesyats, 1993) and (Mesyats, 1995).

The negative ions ionization takes place during flame discharging. Free electrons can be generated and they try to neutralize the positive charge on the cathode spot surface. The reverse electric current can be generated and its value is several times higher than the main discharge current.

The enormous reverse current is caused by the free electron flow and this flow is spread all over the whole cathode spot area. Having passed the near-cathodic potential drop, these electrons penetrate into the skin depth and transform this layer into a liquid film.

Liquid phase generation in the cathode spot

During a cluster explosion, the explosive emission of the negative charge from the cathode is defined by the electric current conducted not by free electrons, but by negative ions. At the same time, the positive charge is by the negative charge flame, and the double electrical layer is formed. The negative ions disintegration in the vacuum arc electric discharges takes place owing to the following reactions:

$$\begin{aligned} &A^- + B \Leftrightarrow AB + e; \\ &A^- + e \Leftrightarrow A + 2e. \end{aligned} \qquad (11)$$

Both reactions (11) occurred in the vapor-gas phase. Based on the first reaction, the concentration of generated free electrons per unit time is equal to:

$$\frac{dn_e}{dt} = k_f n_a^- n_a' = k_f W_{gen.}(1 - W_{gen.}) n_a^2 . \qquad (12)$$

Here k_f – the constant of the first direct reaction (11). The activation energy of the fist reaction (11) is determined by the empiric formula (Benson S., 1962).

$$E_a = 0{,}29D - 22{,}2 \text{ KJ/mole}, \qquad (13)$$

where D – the dissociation energy of the formed diatomic molecule (AB). The dissociation energy is 1.2 eV for Ti_2, and – 2.05 eV for Cu_2 (Radtsig, Smirnov, 1980). So the activation energy is 11.38 kJ/mole for titanium, and 35.16 kJ/mole for copper. The constant of the direct chemical reaction (Benson S., 1962) is:

$$k_f = 2(r_a + r_b)^2 \left(\frac{2\pi k_b T}{\mu} \right)^{1/2} \exp\left(-\frac{E_a}{k_b T} \right). \qquad (14)$$

here r_a and r_b – the covalent radii of the interacting particles, $\mu = \frac{m_a m_b}{m_a + m_b}$ - the reduced mass and m_a, m_b – the interacting particles masses. So the constant of the first chemical reaction (11) under the boiling temperature is $3.245 \cdot 10^{-16}$ m^3/sec for titanium, and $6.283 \cdot 10^{-17}$ m^3/sec for copper.

The mass loss from the solid surface in the presence of negatively charged particles in the flow should be considered as a charged continuum flow with a double electrical layer creation. In this case, the mean free path of every negative ion in the flow must be significantly smaller than the distance, i.e. the negative ions to be removed without the collision in the double electrical layer. So

$$\bar{l} << l_0 = \frac{m_a v_f^2}{2eE_e} . \tag{15}$$

Here m_a – the particle mass in the cathode flame, $E_e = \frac{N_{cl.} e}{S_k \varepsilon_0} W$ - the electric field strength of the charged cathode spot surface S_k and ε_0 = $8.854 \cdot 10^{-12}$ F/m – dielectric vacuum permeability.

There are the electric field intensity values in the double electric layer and its layer size in Table 1.

Table 1 – Main parameters of the double electrical layer
Таблица 1 – Основные параметры двойного электрического слоя
Tabela 1 – Nominalni parametri dvostrukog električnog sloja

Parameters / Cathode material	U_k, V	E_e, V/m	V_f, m/sec	Δ, m	C_p, J/kg·K	ρ_e, V·m	l_0, mm	T_p, K
iron	11.8	481	4324	$2.35 \cdot 10^{-4}$	975	$8.6 \cdot 10^{-8}$	11.2	2650
titanium	6.8	459	4652	$3.55 \cdot 10^{-4}$	684	$4.2 \cdot 10^{-7}$	11.7	2270
copper	11.3	1060	7820	$4.84 \cdot 10^{-4}$	451/513	$1.6 \cdot 10^{-8}$	19.5	2070

The mean free path in the discharge chamber is:

$$\bar{l} \cong \frac{4r_k}{\sqrt{2} N_{cl} W} . \tag{16}$$

where P_C – the cathode flame pressure and r_k – the radius of particles of the cathode flame (atoms for titanium and copper). The mean free path in the cathode flame is $2.76 \cdot 10^{-10}$ m for titanium atoms, $2.28 \cdot 10^{-10}$ m for iron and $1.86 \cdot 10^{-10}$ m for copper, while the distance, the negative ions to be removed from the cathode spot surface, is 5.5 mm, 11 mm and 12 mm for iron, titanium, and copper, respectively. The condition (15) is satisfied, so the cathode flame should be considered as a charged continuum flow. In such a flow, the negative ion range distance from the cathode spot surface is determined not only by the slowing down of the charged particles in the electric field of the double layer, but also by their ionization due to the reaction (11). Then the free electrons concentration along the axis X at the distance x in the layer dx is defined from the chemical reactions and slowing down in the double electrical layer in the following way:

$$dn_e = k_f n_a n_i^- \frac{dx}{v_0 - \frac{eE_e}{m_a v_0} x} . \tag{17}$$

The solution of the differential equation in terms of the boundary condition offers the following approximate dependence for the first and second reaction (11) to occur in the flame

$$n_e(x) = n_{e,0} + 2k_{f,1} n_a grad(n_i^-) \frac{m_a v_0}{eE_e} x;$$
$$n_e(x) = n_{e,x} + 2k_{f,2} n_e grad(n_i^-) \frac{m_a v_0}{eE_e} x, \quad (18)$$

where $n_{e,0}$ – the initial free electrons concentration to be determined by the boiling temperature using the Saha equation.

The first reaction (11) takes place at the beginning and the high-energy ions are generated. After their appearance, the negative ions ionization by an electron impact is stimulated with the decreasing of the quick energy of exciting and forming electrons. Thus, free electrons are generated at the distance of $\Delta l \sim 10^{-2}$ m from the cathode spot surface in accordance with reaction (11). Free electrons under the influence of the positively charged cathode spot surface are directed to the cathode, generating a reverse electric current which is equal to:

$$I = en_{e,x} \bar{v}_e S_k . \quad (19)$$

where $\bar{v}_e$ - the drift electron velocity in the cathode flame plasma.

The following equality is true under stationary conditions on the basis of the charge conservation law

$$n_i^- v_f S_{k,P} = n_{e,k} \bar{v}_e S_k . \quad (20)$$

On the basis of (20), the reverse electric current is equal to the electric current to be generated during a cluster explosion, i.e. to the electric charge separation current with creating a double electrical layer. The difference is that the charge separation current lasts during the clusters explosion, while the reverse current lasts during the creation of the double electrical layer. The direct current is determined by the complex exploded cluster, while the reverse current – by the whole cathode spot surface. As a result, the reverse current density is an order of magnitude lower than the charge separation current.

The complete ionization of negative ions takes place at the distance of the full ions slowing down and in fact the reverse current stops. In this moment, the cathode spot stops its functioning at the given place and the cathode spot is generated alio loco. The cathode spot duration is $2.6 \cdot 10^{-6}$ sec without dependence on the cathode material and it turns out to be the cathode spot lifetime. If the breakdown of the near-cathodic space takes place inside the cathode space, then the cathode spot lifetime increases. This fact was experimentally proved and the most probable value was in a great agreement with data listed here (Kesaev, 1968).

Since the reverse current is transferred by electrons, they can penetrate to the skin depth (Δ). The specific skin layer values for some materials are listed in Table 1. The temperature of the skin layer to be heated, is:

$$T_p = T_0 + \frac{j_k U_k l_0}{\Delta \rho C_p v_f}. \qquad (21)$$

The results of the temperature evaluations and the skin layer to be heated in the cathode layer are listed in Table 1. The surface layer heating in the cathode spot for all the metals is not higher than the boiling temperature and is slightly higher than the melting point.

The cathode spot temperature measured experimentally by an optical pyrometer under different discharge conditions was in the range of 1300 – 2300 K, and 2300 – 3700 K for the copper arc. The temperature evaluations listed in Table 1 are in good agreement with experimental data and are within the melting point and the boiling temperature.

Electronic component temperature in the cathode flame

As a result of the first reaction of (11), the electrons are in the surroundings with average energy, which is equal to the difference between the diatomic molecule dissociation energy and the affinity energy:

$$E_e = D - \theta_i^- . \qquad (22)$$

$E_e = 1.2 - 0.163 = 1.037$ eV for iron, $E_e = 1.2 - 0.079 \approx 1.121$ eV for titanium and $E_e = 2.05 - 1.228 \approx 0.822$ eV for copper. Such average energy of the generated electrons is enough for titanium and copper to effectively ionize by the electron impact the remaining negative ions in accordance with the second reaction (11). These free electrons during negative ions ionization generate a cloud of free electrons with an average energy of (Gretchikhin, Kudryashov, 1970)

$$\overline{\theta}_e = 0{,}55\theta_i^- \text{ eV}. \qquad (23)$$

For example, in the cathode flame, consisting of iron vapor, where the continuous negative ions disintegration due to the electron impact takes place, the average electrons energy in plasma is 0.09 eV, and it corresponds to the electron gas temperature $T_{e,2}$ = 1040 K; , the average electrons energy for the titanium vapor is 0.0435 eV, so the electron gas temperature is $T_{e,2.}$ ~ 505 K; while for the negative copper ions it is ~ 0.452 eV with an average-effective temperature of $T_{e,2}$ ~ 5243 K. So, for the vacuum arc discharge plasma in iron and titanium vapor, the electron gas energy is primarily defined by the first reaction of (11) and the values are 0.570 and 0.616 eV, while the temperatures are ~ 6620 and 7152 K, respectively. For the arc discharge copper plasma, in the first reaction the electrons are generated into plasma with 0.452 eV, while in the second reaction, with 0.675 eV. The second reaction of (11) leads to a quick electron gas temperature drop in the titanium atmosphere, just on the contrary to the copper atmosphere. So, the electron subsystem in the vapor-gas phase of iron, titanium and copper in the cathode flame has an expressed two-humped energies distribution.

Every electron generated after the first reaction (11) excites the following number of direct negative ions by means of the second reaction of (11):

$$\eta_i \approx \frac{1}{3{,}5} \cdot \frac{E_1}{E_2} \int_{3{,}5 \cdot E_2}^{\infty} f(E, T_1) dE . \tag{24}$$

where E_1 – the average energy of the generated electrons owing to the first reaction of (11) and E_2 – owing to the second reaction of (11). The factor 3.5 is determined by the maximum ionization cross-section during the electron impact. (Physical magnitudes: Handbook, 1991)

The final distribution of the generated electrons due to negative ions ionization:

$$f(E)dE = \frac{\left[f_1(E, T_1) + f_2(E, T_2) \right] dE}{\int_0^{\infty} \left[f_1(E, T_1) + f_2(E, T_2) \right] dE} . \tag{25}$$

In copper vapors, the electron gas temperature corresponds mainly to the second reaction of (11). Bearing in mind that there is the electron subsystem in the thermodynamic equilibrium, the average temperature of the vacuum discharge electron component in the copper vapors is ~ 7830 K. The average electron flame temperature was calculated near the surface by modeling the energy fluxes to occur in the cathode spot of the vacuum arc by means of laser, carried out by (Gretchikhin, Minko, Ya, 1967), and it was 7900 K. This coincidence was quite convincing within measurement errors.

So the electron component temperature is defined by the negative ions ionization processes. When the flame leaves the cathode surface drop, it has the temperature which is equal to the cathode material boiling temperature. And the electron flame temperature increases when the distance from the cathode surface increases too. This was experimentally found here (Gretchikhin, Tyunina, 1967), (Gretchikhin, Davydov, Minko, Ya, 1968), (Gretchikhin, Minko, Ya, 1968), (Gretchikhin, 1974).

The following fact was found experimentally in these studies (Gretchikhin, Tyunina, 1967), (Gretchikhin, Davydov, Minko, Ya, 1968), (Gretchikhin, Minko, Ya, 1968), (Gretchikhin, 1974). High-power continuous radiation can appear near the cathode surface, but the spectral lines and bands radiation of atoms and molecules are absent. So the flame emission near the cathode surface corresponds to the condensed media, i.e. in this case it is a liquid phase. The separation between the vapor-gas and the liquid phase takes place as the distance from the cathode surface increases. The temperature quickly increases in the vapor-gas phase and atoms and molecules radiation takes place, while the liquid phase radiation disappears due to its cooling under the dispersion.

The electrons are directed onto the cathode as the negative ions disintegration and they neutralize the induced positive charge, spread all over the cathode spot. The positive ions from the discharge gap cannot reach the cathode surface, since they are neutralized during the impact with the cathode flame. The current from the discharge onto the cathode stops and so the near-cathodic area breakdown takes place in the other place and this is determined by the fact that the opposite currents are mutually repelled.

If we assume that there is vacuum arc discharge plasma in the thermodynamic equilibrium, the ion plasma composition in the cathode flames vapor inside the discharge gap can be defined by the Saha equation:

$$\frac{n_{i+1}n_e}{n_i} = C' \frac{2Z_{i+1}}{Z_i} \exp\left(-\frac{\varepsilon_{i+1}-\varepsilon_i}{k_b T}\right), \tag{26}$$

where $C' = \frac{(2\pi m_e k_b T)^{3|2}}{h^3} = 2{,}415 \cdot 10^{21} T^{3/2}$ – the dimensional constant; Z_{i+1}, Z_i – the statistical partition function; $\varepsilon_{i+1}, \varepsilon_i$ - the energy of state *i*+1 and *i* the degree of ionization of plasma particles, k_b – the Boltzmann constant, *T* – the corpuscular heated vapor temperature, m_e – the electron mass and *h* – the Planck constant.

Table 2 – Ions per cent of different degree of ionization
Таблица 2 – Процент ионов разной кратности ионизации
Tabela 2 – Procenat jona različitog stepena jonizacije

Element	U_k, V	Ions fraction, %		
		I	II	III
Ti	6.8	27/27	72/67	1/6
Cu	11.3	30/30	68/54	1.9/15

The direct measurements of the composition by percentage of ions with different degrees of ionization were carried out in the vacuum arc discharge at a current of 100 A. (Mrochek, Vershina, Ivashchenko, et al, 2004) and (Kolesnik, Kolesnik, 2009) and the results are listed in Table 2 (the lower row). If we make the association with the composition by percentage of ions with the first degree of ionization, then, in accordance with the Saha equation, the temperature is ~ 4100 K for the titanium cathode and 6830 K for the copper cathode. Under these temperatures, the composition measurements by percentage of ions with consequent degrees of ionization in the vacuum discharge are listed in Table 2 (the upper row). The found results of the composition by percentage using the Saha equation do not obviously correspond to the composition by percentage obtained by direct measurements. It indicates that the generated plasma in the vacuum arc discharges is essentially no equilibrium. There is a difference between the electronic temperature and the atomic temperature obtained by the Saha equation. The electronic component in the vacuum arc plasma discharge has the electrons with different energy, i.e. their generation takes place due to the different mechanisms on the basis of reactions in (11).

Electric current reverse motion in the cathode flame under the tangential magnetic field

It was found experimentally by Shtark and then by Keasev in detail, that the reverse current rate of the cathode spot under the longitudinal magnetic field depends on:

- cathode material;
- cathode material surface condition;
- arc current;
- oxide film;
- cathode temperature; and
- pressure of reaction discharge gas in the chamber.

The simultaneous explosions of several clusters (emission cells systems) in the cathode spot leads to the double electrical layer generation above the cathode spot of a sufficiently great size (l_0 Table 1). The electrical current of neutralization of the positive charge on the cathode spot surface in the double electrical layer is directed oppositely to the principal discharge current. The Ampere force appears under the magnetic field superposition along the cathode surface:

$$\vec{F}_A = -\left[\vec{J} \cdot \vec{B}\right] S_k l_0 . \tag{27}$$

Hence, the cathode spot rate of motion is:

$$v_n = \frac{F_A}{m_k}\frac{l_0}{v_f} = -\frac{l_0^2}{m_k v_f}\left[\vec{J} \cdot \vec{B}\right] S_k\,, \qquad (28)$$

where m_k - the cluster mass.

Let it be examined in what way the above-mentioned changing parameters have the influence on the cathode spot velocity of reverse travel under the longitudinal magnetic field.

The *material cathode* dependence is directly proportional to the dependence on the squared double electrical layer width and inversely proportional to the dependence on the cluster mass and flame rate of motion for different materials. The titanium cathode spot rate of motion is 5.8 times higher than the one for iron, while for copper it is 7.2 times higher.

The dependence on the *surface condition (i.e. roughness)* occurs when the cathode spot fails and recovers in another area, but the transition from one hill to another with a roughness increase cannot take place and the cathode spot motion stops.

The cathode spot rate of motion increases directly proportionally to the *arc current* under constant other parameters.

The *oxide film* on the cathode material prevents the near-cathodic space breakdown and it can lead to the quick cathode spot motion stop.

The *cathode temperature increase* leads to the thermo emission current increasing, which reduces the reverse electron neutralization current of the double electrical layer. Therefore, it decreases the Ampere force and, consequently, the cathode flame rate of reverse motion.

The increase of the pressure of reaction discharge gas in the chamber leads to the increase of the positive ions concentration in the discharge gap. The cathode flame is bombarded by positive ions, the negative ions concentration is decreased and, consequently, free electrons concentration during the negative ions ionization is decreased, too. The reverse electric current is reduced and the cathode spot rate of reverse motion is decreased.

Conclusion

Therefore, the investigations of the vacuum arc discharge with the cold cathode allowed finding out a new phenomenon. During the generation of a defined complex clusters explosion in the cathode spot, a fraction of certain atoms is as negative ions. As a result of this, a double electrical layer is formed above the cathode spot, and its neutralization leads to reverse current of free electrons generated owing to the negative ions ionization.

This phenomenon in the cathode spots of the arc discharges allowed finding out the following:

1. The negative charged flame with frequency, defined by the cathode spot life time discharges from the cathode spot,
2. The double electrical layer is generated above the cathode spot surface, which is neutralized by the reverse electrical current, generated by free electrons owing to the negative ions ionization,
3. All the phenomena taking place during the cathode spot motion under the longitudinal magnetic field are explained by the high-power reverse neutralization current generation of the double electrical layer.

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ДВОЙНОЙ ЭЛЕКТРИЧЕСКИЙ СЛОЙ В КАТОДНОМ ПЯТНЕ

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ОБЛАСТЬ: материалы, нанотехнология, материаловедение на наноуровне
ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: анлийский

Краткое содержание:

Установлено новое явление, заключающееся в образовании над поверхностью катодного пятна двойного электрического слоя, нейтрализация которого приводит к обратному току свободными электронами, образующихся вследствие ионизации отрицательных ионов. Отрицательно заряженный факел из катодного пятна периодически пропадает и возникает. Этот колебательный процесс определяет длительность существования катодного пятна. Обратное движение катодного пятна в продольном магнитном поле происходит вследствие образования обратного мощного тока нейтрализации двойного электрического слоя электронами, возникающих при ионизации отрицательных ионов в катодном факеле.

Ключевые слова: *электрический разряд, катодное пятно, катодный факел, отрицательные ионы, двойной электрический слой.*

DVOSTRUKI ELEKTRIČNI SLOJ U KATODNOM SPOTU

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OBLAST: materijali, nanotehnologije
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Sažetak

U radu se opisuje novootkrivena pojava stvaranja dvostrukog električnog sloja iznad površine katodnog spota. Njegova neutralizacija dovodi do reverzne struje slobodnih elektrona, generisane usled jonizacije negativnih jona. Negativno naelektrisan plamen katodnog spota periodično se stvara i gasi, tako da je dužina postojanja katodnog spota definisana ovim oscilirajućim procesom. Reverzno kretanje katodnog spota u longitudinalnom magnetnom polju dešava se zahvaljujući generisanju reverzne struje neutralizacije velike snage dvostrukog električnog sloja pomoću elektrona koji nastaju tokom jonizacije negativnih jona u plamenu katode.

Ključne reči: *električno pražnjenje, katodni spot, plamen katode, negativni joni, dvostruki električni sloj.*

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RESEARCH INTO THE CAUSES OF OVERHEATING OF BEARINGS AND SOLVING THE PROBLEM OF FURTHER OPERATION OF A 450 kVA SHORT BREAK DIESEL-GENERATING SET AT BELGRADE AIRPORT

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Abstract:

The paper presents the research into the causes of increased heating in bearings and troubleshooting further exploitation of a Short Break diesel generating set with a power of 450 kVA at Belgrade Airport. The diesel engine is a type of Short Break, which means that in the event of an interruption in the electricity supply from the city network, there is a certain interruption of about 40 seconds until diesel generators start to supply electricity to the equipment and systems at Belgrade Airport. The main function of the diesel engine is to serve as a backup source power supply for devices and systems in case of limited visibility (lighting around the runway and many other devices and systems).

Key words: *diesel generating set, elevated warming in bearings, measurement and analysis of vibration, vibration levels, vibrodiagnostics, vibration parameters, technical correctness of diesel generators .*

Introduction

The paper presents research into the causes of increased warming of bearings as well as the solution for continuing the exploitation of a 450 kVA Short Break diesel generating set at Belgrade Airport.

This diesel engine is of a *Short Break* type, which means that in the event of an interruption in the electricity supply from the mains, there is some interruption of 40 seconds until powering devices and systems start using diesel generators.

The main function of the diesel generator is to serve as a backup power supply for devices and systems in conditions of limited visibility at Belgrade Airport (lighting around the runway and many other devices and systems), in order to increase air traffic safety.

Description of the unit and the measuring points on the 450 kVA Short-Break diesel-electro generating set

A Short-Break generating set is presented in Fig.1 (*Technical documentation for Short Break generating sets, 1974*). The diesel generator elements were mounted on a frame, i.e. a chassis of the electric generator: a diesel engine and a flywheel connected with a diesel engine by means of an MBM 500 electromagnetic coupling (see Fig. 2) of the German manufacturer Stromag (*Technical documentation for electromagnetic couplings,* Stromag, 1973), (Flender Betriebsanleitung BA 3100 DE 07.03 für Hochealastiche Kupplung, Bocholt, Deutschland, 2003).

The generator and the electric motor are connected to the generator flywheel with rubber flexible couplings, the German manufacturer Vulkan (*Technical documentation for flexible couplings*, Vulkan, 1973).

The electromotor drives the generator through the belt transmission. In case of deterioration of visibility conditions for aircraft landing at Belgrade Airport, staff on duty put the power generator into operation, even if there is no interruption in the electricity supply from the city power grid. This is a security measure for safe air traffic.

The electric motor drives the generator and the generator flywheel. Power devices and systems continue to be supplied from the city power grid. In the event of power interruption from the city grid, the diesel engine is immediately put into operation over an electromagnetic coupling and it provides further functioning of the power set. In this case, all the devices and systems are supplied with electricity from the generator unit.

The diesel generating set is from the German production company MWM - *Germany Motoren Werke Mannheim*, (*Technical documentation for diesel engines*, MWM, 1973).

During the work of the diesel engine, the problem of increased warming of flywheel bearings occurred, endangering the further exploitation of the generating sets.

Many of these phenomena can be detected with a vibrodiagnostic analysis of the unit.

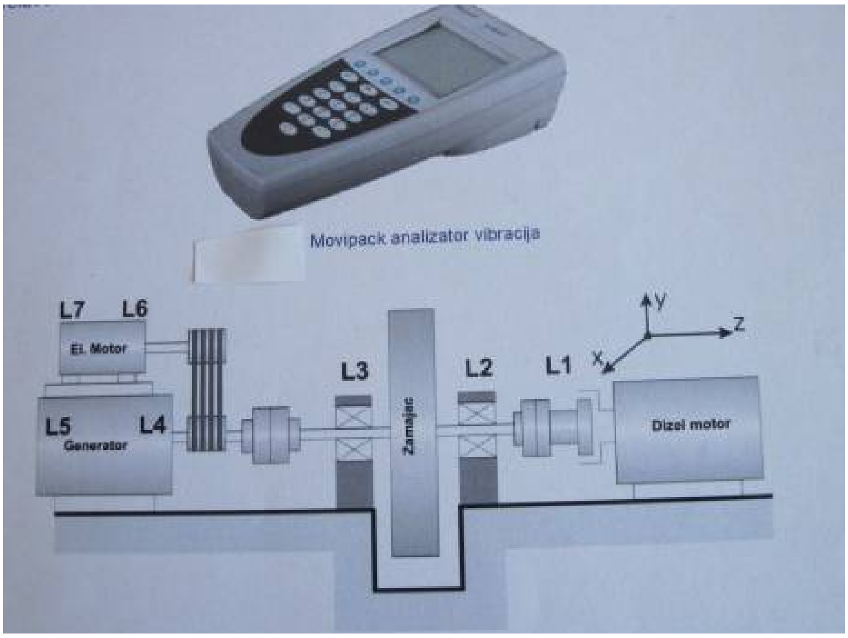

Figure 1 – Schematic presentation of the unit and the measuring points on the 450 kVA Short-Break diesel-electric generator
Рис. 1 – Схема электростанции и расположение измерительных точек на дизельной электростанции типа Short-Break, с мощностью 450 кВА
Slika 1 – Šema postrojenja i merna mesta na dizel-elektroagregatu tipa Short-Break, snage 450 kVA

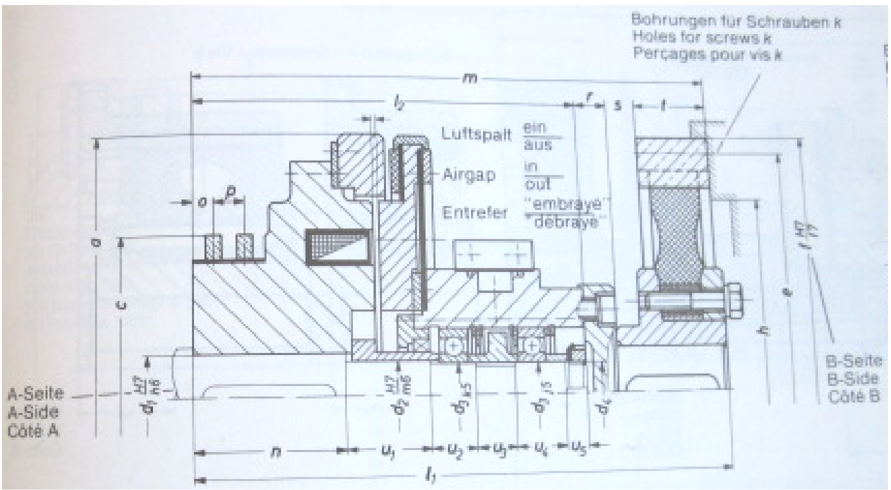

Figure 2 – Electromagnetic coupling of the German manufacturer Stromag, MBM 500 type
Рис. 2 – Электромагнитная муфта немецкого производителя Stromag, MBM 500 type
Slika 2 – Elektromagnetna spojnica nemačkog proizvođača Stromag tip MBM 500

Description of the measuring equipment, measurement points and recorded values

This document is a detailed plan for vibrodiagnostic measurements and a subsequent analysis. We performed the measurements in the mode of the electric motor drive and in the diesel engine drive mode (Žegarac, 2010).

The description of the measuring chain:

- dual channel portable vibration analyzer MOVIPACK, Premium, French manufacturer, 01 dB (Figure 1),
- piezoelectric accelerometers with integrated electronics (ICP): ASH201, French manufacturer ,01 dB, and SA6200, US manufacturer Metrix,
- for recording generator speed: Movipack contactless integrated laser speed sensor,
- for measuring bearing temperatures: Movipack integrated non-contact laser pyrometer,
- for the post-processing of the results: Vibrograph Premium software, French manufacturer 01 dB.

The vibrations were measured on all seven bearings in all three coordinate directions. The vibration measurements included recording of the following values:

1. First RMS value of vibration velocity expressed in mm / s. Taking such defined summary vibrations is prescribed by reference standard ISO 10816, which also prescribes the limits of permissible vibration levels for a given machine (Ličen, 2003). RMS- Root Mean Square - value.
2. Kurtosis second factor: the scalar factor that directly shows the degree of damage to rolling bearings, defined in such a way that its value does not depend on the speed and load of a machine.
3. Time display of vibrations (frequency range up to 10 kHz, 16,383 points).
4. Frequency display of vibrations (frequency domain to 1 kHz, 3,200 frequency lines) as follows:
   - The FFT frequency spectrum with amplitudes expressed by the RMS value of vibration velocity in mm / s.
   - On the bearings, the cross-spectra of vibrations were recorded in two orthogonal radial directions.
   - In the adjoining bearings, the cross-spectra of axial vibrations were recorded.
5. Measurement of the generator speed.
6. Temperature of the generator bearing housing.

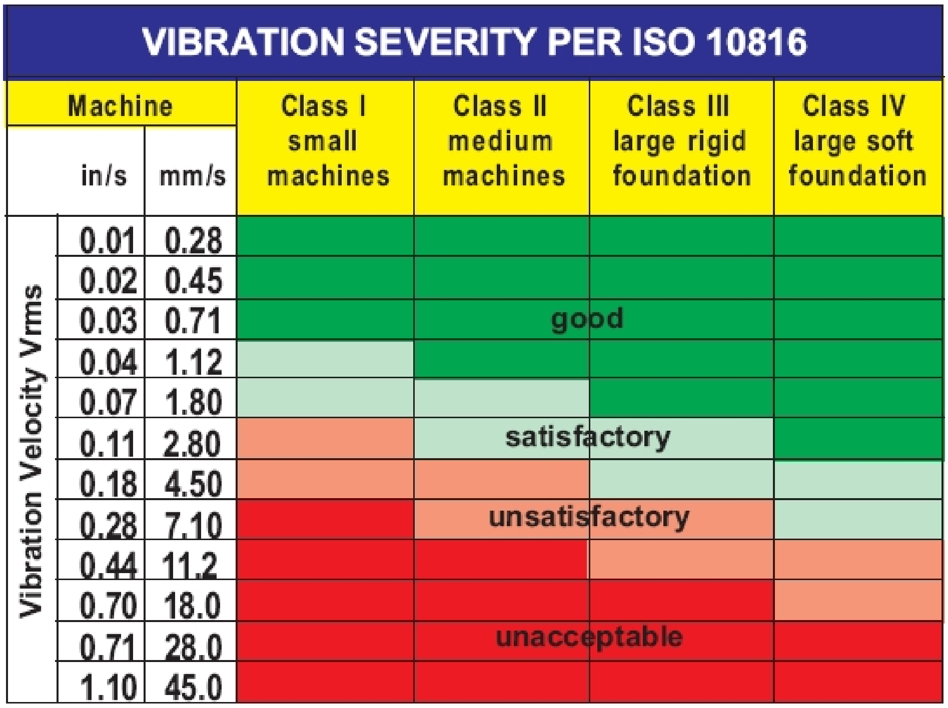

Figure 3 – Recommendations for vibrations according to ISO 10816
Рис. 3 – Вибрационное состояние согласно стандарту ISO 10816
Slika 3 – Preporuke za vibracije po standardu ISO 10816

Results of the measurements and their analysis

Figures 1-4 give the graphical presentations of the frequency spectra of the recorded vibrations as well as their analysis in the directions x, y and z, for the L1 bearing- electromagnetic coupling, for the L2 bearing – the flywheel side to the diesel engine, for the L3- bearing the flywheel side to the generator.

Because of this work extensiveness, the other results of the vibration measurements will be displayed only in tables (Žegarac, 2010).

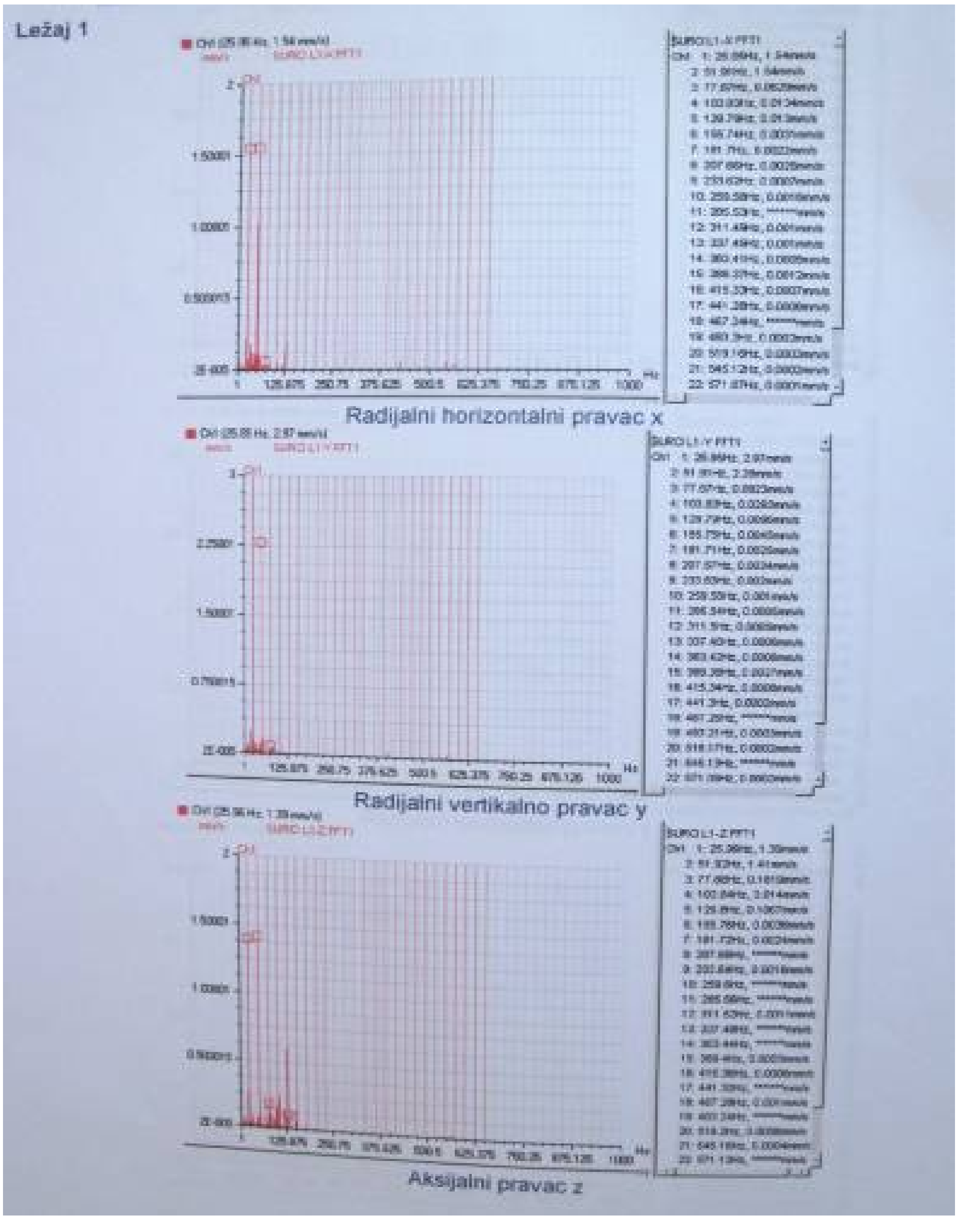

Figure 4 – Frequency spectrum of the recorded vibrations and their analysis for the L1 bearing
Рис. 4 – Спектр замеренных вибраций и анализ вибраций подшипника L1
Slika 4 – Frekventni spektar snimljenih vibracija i njihova analiza za ležaj L1

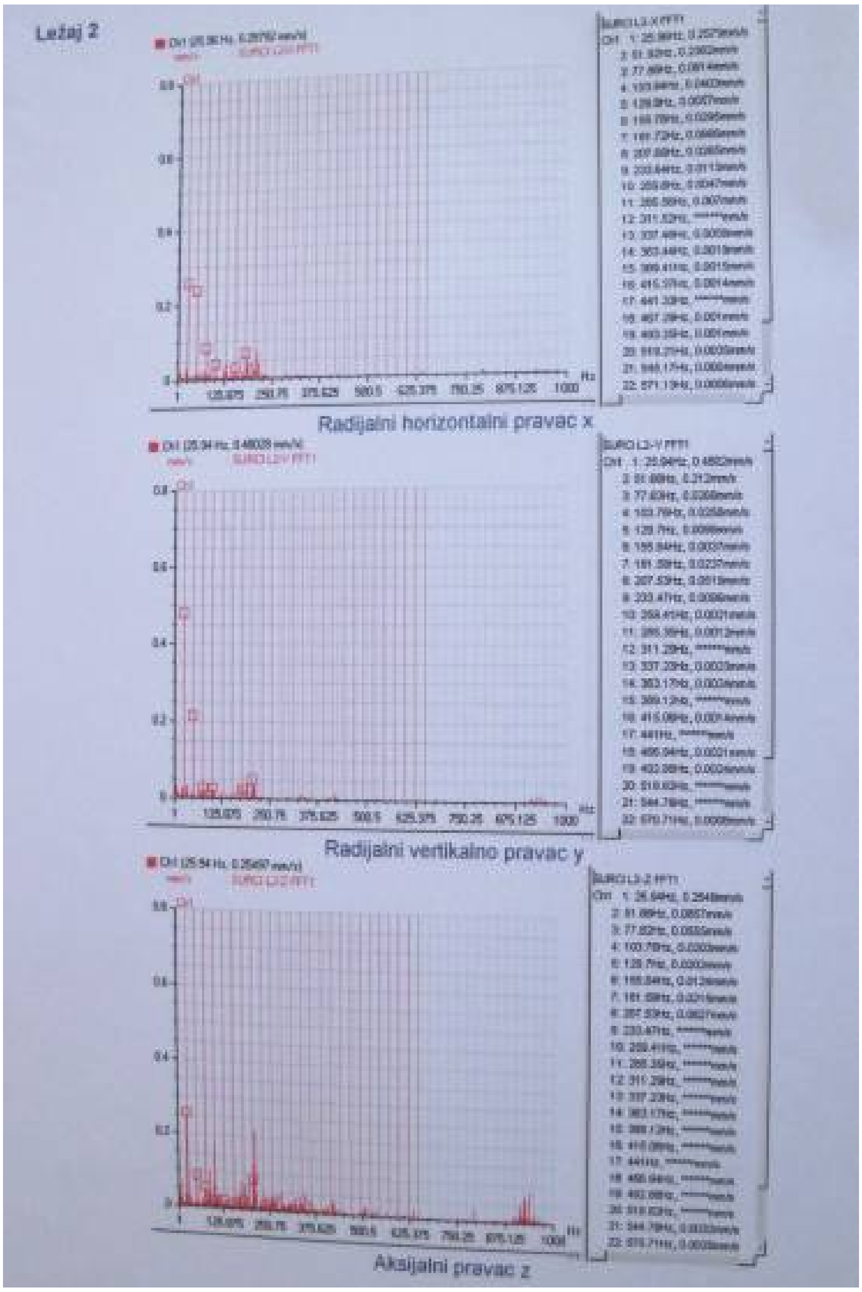

Figure 5 – Frequency spectrum of the recorded vibrations and their analysis for the L2 bearing
Рис. 5 – Спектр замеренных вибраций и анализ вибраций подшипника L2
Slika 5 – Frekventni spektar snimljenih vibracija i njihova analiza za ležaj L2

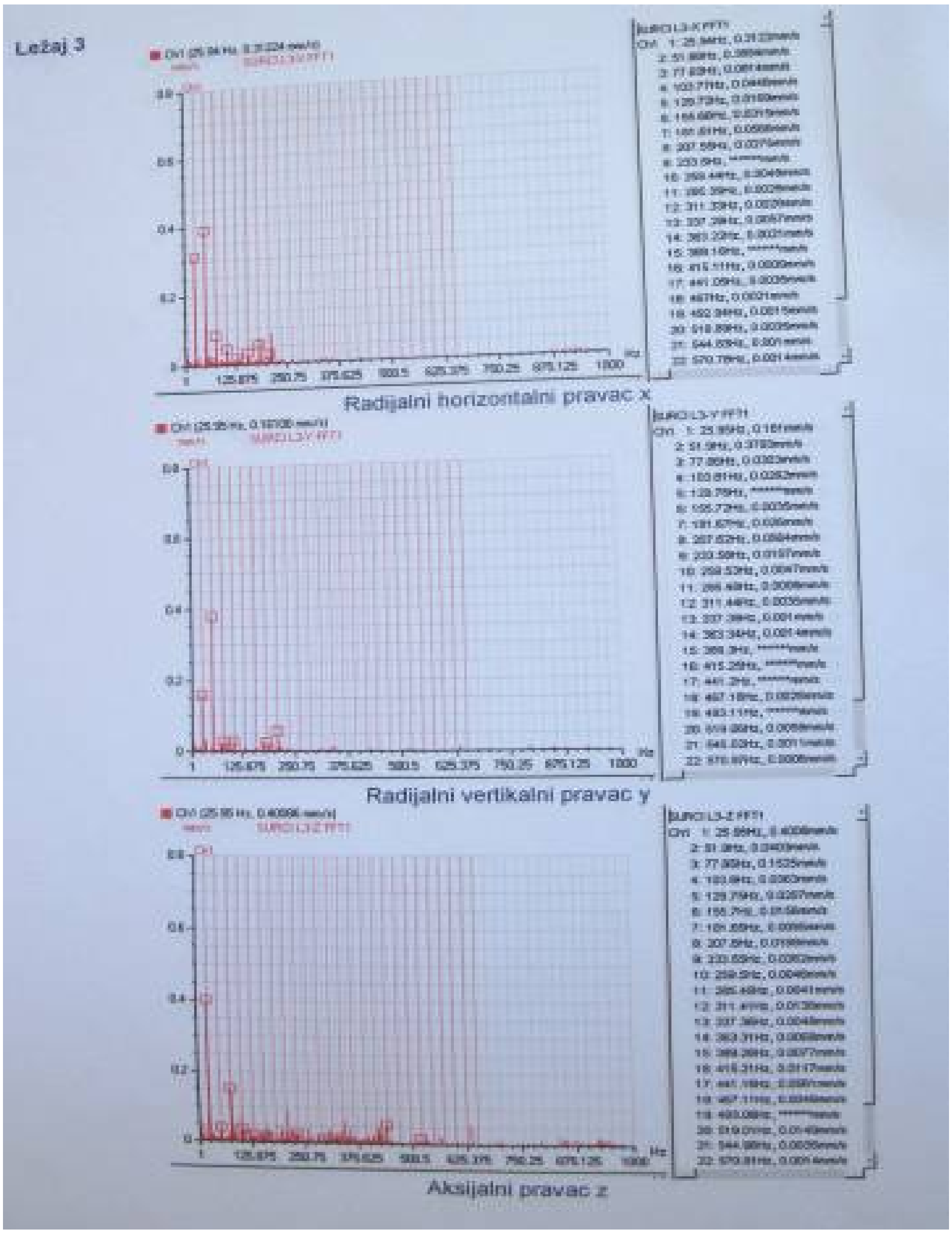

Figure 6 – Frequency spectrum of the recorded vibrations and their analysis of the L3 bearing
Рис. 6 – Спектр замеренных вибраций и анализ вибраций подшипника L3
Slika 6 – Frekventni spektar snimljenih vibracija i njihova analiza za ležaj L3

Table 1 presents the results of the measurements of the vibration scalar values:

Tabela 1 – Results of the measurements of the scalar values of vibrations
Таблица 1 – Результаты измерений скалярных величин вибрации
Tabela 1 – Prikazi rezultata merenja skalarnih veličina vibracija

	Horizontal x		*Vertical y*		*Axial z*		*Assessment by ISO 10816*	*Bearing condition*	*Temperature °C*
	RMS mm/s	*Kurt*	*RMS mm/s*	*Kurt*	*RMS mm/s*	*Kurt*			
L1	*2.34*	*2.96*	*3.84*	*2.94*	*2.22*	*3.19*	*Acceptable*	*Satisfactory*	*56*
L2	*0.743*	*3.11*	*1.02*	*3.21*	*0.772*	*3.08*	*Good*	*Satisfactory*	*79*
L3	*0.996*	*2.98*	*0.974*	*3.36*	*0.782*	*7.57*	*Good*	*Satisfactory*	*76*
L4	*0.659*	*3.03*	*0.688*	*3.11*	*1.3*	*3.05*	*Good*	*Satisfactory*	-
L5	*0.709*	*3.44*	*2.3*	*2.85*	*1.85*	*2.96*	*Good*	*Satisfactory*	-
L6	*1.58*	*3.17*	*2.83*	*2.88*	*3.53*	*4.09*	*Acceptable*	*Satisfactory*	-
L7	*1.51*	*3.11*	*2.08*	*3.04*	*4.73*	*3.56*	*Acceptable*	*Satisfactory*	-

According to ISO standard 10816-3, the test of this machine belongs to class 4, with the following levels and areas of tolerance limits of vibrations:

<2.8 mm / s → GOOD
<7.1 mm / s → acceptable
<18 mm / s → ONLY ACCEPTABLE
>18 mm / s → unauthorized

In the same way, the measurements were performed in the mode of the diesel engine drive.

Conclusion

Based on the summary levels of vibrations in accordance with ISO standard 10816, the condition of this machine can be assessed as satisfactory.

The vibrations on the bearings in the diesel engine drive mode did not significantly change. However, the temperature of the L2 bearing on the flywheel on the diesel engine side significantly increased to 96 °C and the L3 bearing had a temperature of 80 °C, which was a sign that the problem was in the generator flywheel bearings.

The permissible L2 bearing temperature, according to the technical documentation for the generator in the diesel engine drive mode, is 85 ° C (*Technical documentation for Short Break generating sets, German company* MWM, 1974).

Troubleshooting further operation of diesel-generator sets

It was concluded that the further exploitation of the generating set would be very risky. It was obvious that the main problem was in the bearings of the generating set flywheel. The next step was to open both flywheel bearing housings to visually inspect the bearings. It was noticed that both bearings had changed their colour. The outer and inner rings of both bearings had changed their colour into dark or black, as a result of bearing elevated temperatures. These bearings are self aligning (*Germany Pendelrollenlager*), spherical rollers, in double rows, with a brass cage for better heat dissipation (Hauptkatalog SKF Gruppe-Pendelrolenlager, pp.695-777, Sweeden, 2007).

Heat effects and color changes were more pronounced in the bearing on the side of the diesel engine, because it suffers greater impact dynamic loading when the diesel engine is switched into operation.

The user of the generating set had already thought of disassembling the elements, the electromagnetic coupling and the generator flywheel and of replacing the bearings in the coupling as well as the bearings on the flywheel and of replacing the flexible coupling (rubber elements) between the flywheel and the generator of the generating set, since it had not been done since 1974, when the unit was put into operation.

However, the main problem was related to the dismantling of the generating set elements. The problem was the height of the aggregate hall, which was only 2.9 meters. The hall was not equipped with a crane hoist. The user was trying to devise a system of lifting the elements using some scaffolding which were very heavy and could not be entered into the aggregate hall through the front door.

To solve the problem, the author of this paper came up with the idea to construct scaffolding for dismantling assemblies.

The system for dismantling the parts of generators is shown in Figure 7 (Žegarac, 2009).

The system consisted of a handheld device for lifting that is set in place, position (1) in the figure, and three-pronged scaffolding.

Each leg of the scaffolding consisted of two pipes, position (3), that could be pulled in and pulled out, (telescopic system) thus providing the required height for lifting assemblies. At the top of the scaffolding, the telescopic tubes were fastened to the star element, position (4).

After the determination of the required height for lifting assemblies, the pipes were fixed with cross pins, position (2). In order to avoid slipping of the pipes on the concrete floor, holes were drilled in the floor of the aggregate hall and equipped with metal profiles, position (5), ∅ 10 mm in diameter. One part of the metal profile enters the concrete floor and the other part goes into the metal pipe. In this way, the pipes were prevented from slipping on the concrete floor during lifting.

The assemblies were lifted using a hoist tied to a metal ring on the top of the scaffolding where three pipes were connected. The mass of the generator flywheel is 900 kg.

When the generator flywheel was lifted to a certain height, it was rotated for 90° and lowered onto the unit chassis. After that, the electromagnetic coupling, weighing 600 kg, was dismantled.

Both bearings on the flywheel were replaced as well as the bearings in the electromagnetic coupling.

Slight traces of wear and tear were noticed on the internal and external rings of both bearings.

The thermal effect of overheating was very pronounced. The good thing was that the cages were made of brass, so they had better properties of heat dissipation and cooling. If the cages had been made of steel, accidents cannot have been avoided.

We had such an experience with the aggregate at Airport Tivat in Montenegro (Žegarac, Ličen, Zuber, 2000).

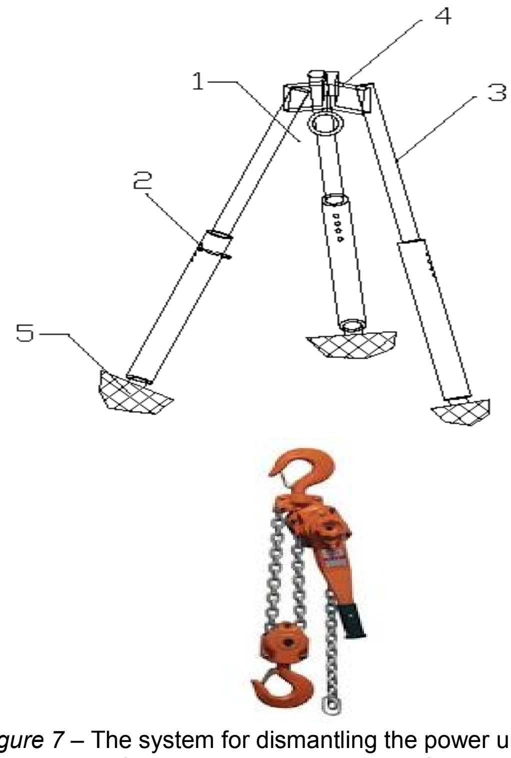

Figure 7 – The system for dismantling the power unit assembly
Рис. 7 – Изображение системы для разборки узла агрегата
Slika 7 – Prikaz sistema za demontažu sklopova agregata

What was a problem with these bearings?

Flywheel bearings are lubricated with grease of certain gradation. On bearing housings, there is a system to extract excess grease by pistons and rods built in bearing housings. It often happens that the staff in charge, as soon as they hear some sound in the bearing, immediately lubricate it. They do not have enough knowledge in this field. It is important to know that, if a bearing is soaked in grease, it warms up, and, if there is not enough grease, friction occurs.

Different types of bearing grease were used, of various basic types and gradations. When the bearing is lubricated with some other grease type, chemical *disintegration* occurs and the lubricant properties are lost. Users need to know that oils and grease from different manufacturers should never be mixed, even when they have the same gradation. Each manufacturer of oil and grease adds its own additives that are different from those of other manufacturers.

The generator was moved back so that the rubber flexible coupling, Vulkan type, could be replaced. The flexible coupling consists of two plate-shape parts.

This flexible coupling had never been changed. It is known that rubber products are subject to aging and should be changed every 4 years, which was not the case here.

After the replacement, the elements were assembled and centered. The aggregate was again put into operation and tested in the electric motor drive mode and the diesel engine drive mode at maximum power. Vibrations and bearing temperatures were measured in the same places. The vibrations of the system were considerably lower than before replacing the bearings and other parts of the aggregate. The temperature of the bearing on the generator flywheel on the side to the diesel engine was 85°C, and that of the flywheel bearing on the generator side was 76° C. The values of vibration and temperature parameters matched the performance standards prescribed by the generator technical documentation.

In this way, the problem of research into the causes of elevated temperatures of generator bearings was successfully solved as well as the problem of further exploitation of the generator (Žegarac, Ličen, Zuber, 1999).

Conclusion

This paper presents a very useful example of research into the causes of increased warming of bearings and of the troubleshooting for further exploitation of the diesel generating set of Short-Break type at Belgrade Airport. Modern vibrodiagnostic methods were used for determining the technical condition of the unit.

A very *interesting* system for lifting and dismantling generator elements was designed. It is a portable system that is assembled in an aggregate hall on site.

The main characteristic of this easily-usable system is a possibility of adjusting the height of lifting and dismantling parts of generators.

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ИССЛЕДОВАНИЕ ПРИЧИН ПЕРЕГРЕВА ПОДШИПНИКОВ И РЕШЕНИЕ ПРОБЛЕМЫ ДАЛЬНЕЙШЕЙ ЭКСПЛУАТАЦИИ ДИЗЕЛЬНОЙ ЭЛЕТРОСТАНЦИИ ТИПА SHORT BREAK МОЩНОСТЬЮ 450 кВА В ГП АЭРОПОРТ БЕЛГРАД

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ОБЛАСТЬ: машиностроение, электротехника
ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

В данной работе представлены исследования причин перегрева подшипников и решение проблемы дальнейшей эксплуатации дизельной электростанции типа Short Break мощностью 450 кВА в ГП Аэропорт Белград.

Дизельная электростанция типа Short Break в случае перебоя электроснабжения от городских сетей останется без питания в течение 40 секунд, пока системные установки Аэропорта Белград не начнут заряжаться с помощью дизель-генераторов.

Дизель-генератор является резервным источником электропитания устройств и систем в условиях ограниченной видимости (освещение взлётно-посадочной полосы, рулёжной дорожки и пр.).

Ключевые слова: *дизельные электростанции, перегрев подшипников, измерение и анализ вибраций, уровень вибраций, вибродиагностика, вибрационные параметры, техническое состояние дизельных электростанций.*

ISTRAŽIVANJE UZROKA POVIŠENOG ZAGREVANJA LEŽAJEVA I REŠAVANJE PROBLEMA DALJE EKSPLOATACIJE DIZEL-ELEKTROAGREGATA TIPA SHORT BREAK, SNAGE 450 kVA, U JP AERODROM BEOGRAD

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OBLAST: mašinstvo, elektrotehnika
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Rezime

U radu su prikazana istraživanja uzroka povišenog zagrevanja ležajeva i rešavanje problema dalje eksploatacije dizel-elektroagregata tipa Short Break, snage 450 kVA, u JP Aerodrom Beograd.

Dizel-agregat je tipa Short Break, koji u slučaju prekida u napajanju električnom energijom iz gradske mreže, nakon oko 40 sekundi, počinje da napaja uređaje i sisteme na Aerodromu Beograd.

Osnovna funkcija dizel-agregata jeste da služi kao rezervni izvor napajanja uređaja i sistema u uslovima ograničene vidljivosti (rasveta oko piste i mnogi drugi uređaji i sistemi).

Ključne reči: *dizel-elektroagregat, povišeno zagrevanje ležajeva, merenje i analiza vibracija, nivoi vibracija, vibrodijagnostika, vibracioni parametri, tehnička ispravnost dizel-agregata.*

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USE OF THE FUZZY AHP - MABAC HYBRID MODEL IN RANKING POTENTIAL LOCATIONS FOR PREPARING LAYING-UP POSITIONS

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ARTICLE LANGUAGE: English

Summary:

The paper proposes a hybrid model, FAHP-MABAC. The fuzzyficated Saaty's scale with the AHP method (FAHP) is used for defining the weight coefficients of criteria. The MABAC method is applied in evaluating and ranking the alternatives. This hybrid model is developed in order to support decision making while selecting locations for the preparation of laying-up positions (facilities intended for concealment, protection and maneuvering of military ships).

Key words: *location selecton, fuzzy AHP, MABAC.*

Introduction

The decision making process is usually followed by a large number of uncertainties. This is particularly characteristic of combat operations involving different units and different types of modern military equipment. Therefore, the development of a decision making model has an important role in the operational planning process.

This paper presents a hybrid model using the fuzzyficated Saaty's scale, the analytic hierarchy process method (FAHP) and the MABAC (Multi-Attributive Border Approximation area Comparison) method - the FAHP-MABAC model. Herein are briefly explained the methods used, with a more detailed elaboration of the fuzzyfication of Saaty's scale and the MABAC method. The hybrid FAHP-MABAC model is made in order to support decision making while choosing the location for the development of laying-up positions.

Problem description

During the preparation of combat operations, various kinds of masking are carried out in order to protect forces and resources from enemy's surveillance and effects. This term is defined in the literature in different ways, but essentially it refers to the same or similar activities. The most general definition is provided in the Military Lexicon (Vojni leksikon, 1981, p.275), where the term *masking* refers to "a set of measures and procedures used to conceal the intentions of one's own forces, movements and placements of combat and other means and the facilities from the enemy's surveillance from land, sea, air and cosmic space, achieving a surprise effect and deceiving the enemy." In other words, by means of masking, the enemy is misled into erroneous conclusions, decisions and actions (Milosavljević, 1985, p.129). This is accomplished in several ways- by hiding, concealment or deception (Rkman, 1984, pp.21-26).

A large number of war experiences speaks in favor of the importance of including masking in combat operations. In this regard, the Vietnam War (1954-1975) is extremely impressive. Also, the experience from the wars in the former Yugoslavia, and especially the NATO bombing of Yugoslavia in 1999, demonstrated how even small-scale masking protection techniques in the era of electronic means for surveillance can result in the reduction or even avoidance of losses.

One of the elements of masking is the development of laying-up positions. These are "arranged parts of the coast that provide concealment, a partial degree of protection and quick maneuver of river flotilla forces" (Vojni leksikon, 1981, p.276), i.e. military ships. In accordance with the general purpose of masking, the main objective of construction of laying-up positions is leading the enemy to erroneous conclusions, decisions and actions related to the deployment of our military ships (Bozanić et al., 2015a).

The literature generally describes a part of criteria that a location of laying-up positions should meet. However, their precise definition, weight values and relationships are missing. Therefore, the decisions made on this problem rely on the knowledge and experience of decision makers (DM) and their associates. Such a situation represents a field for the application of multiple criteria methods.

Description of the methods used in the hybrid FAHP-MABAC model

The described model is based on the knowledge of several decision-making methods (areas), fuzzy logic, the AHP method (Saaty's scale) and the MABAC method. Fuzzy logic covers successfully vagueness and uncertainty that are often present in decision-supporting models. The Saaty's scale, which is an indispensable part of the AHP method, shows good results in the criteria weight coefficients defining, and it is increasingly applied with other methods (Ertuğrul, Karakaşoğlu, 2009), (Das, et al., 2012), (Beikkhakhian, et al. , 2015), (Zhu, et al., 2015), (Sara, et al., 2015), (Kazan, et al. 2015), (Knežević, et al., 2015). The MABAC method provides stable (consistent) solutions and it represents a reliable tool for rational decision-making (Pamučar, Ćirović, 2015).

Fuzzy logic and fuzzy sets

In fuzzy logic, unlike in conventional sets, belonging of one element to the given set is not precisely defined; the element can be more or less a part of the set (Pamučar, et al., 2011a, p.594). Therefore, fuzzy logic is closer to human perception than conventional logic (Pamučar, et al., 2011a, p.594). This feature allows fuzzy logic to quantify the information which, in classic logic, is considered imprecise. The existence of apparently imprecise information, which in fuzzy logic is very well handled, frequently occurs in social sciences, including decision-making processes.

The creator of fuzzy logic is Lotfi Zadeh. In a series of papers, he presented the basics of fuzzy logic (Zadeh, 1965), (Zadeh, 1972), (Zadeh, 1973) and others. These basics were enough to empower fuzzy logic and now cause it to constantly evolve and increasingly be applied in practice. For the purposes of this paper, several segments of fuzzy logic are significant: definition of fuzzy set, selection of a membership function form and confidence intervals.

The fuzzy set *A* is defined as a set of arranged pairs

$$A=\left\{\left(x,\mu_A(x)\right)\middle|x\in X,0\le\mu_A(x)\le 1\right\} \tag{1}$$

where:

- *X* - is a universal set or a set of considerations based on which a fuzzy set A is defined;

- $\mu_A(x)$ is a membership function of the element *x* ($x\in X$) to the set A; A membership function can have any value between 1 and 0; so, as the value of the function is closer to 1, the membership of the element x to the set A is greater, and vice versa.

Each fuzzy set is completely and uniquely defined by its membership function (Zadeh, 1965). Membership functions may have different forms, but the most commonly used are triangular, trapezoidal and Gaussian. The selection of the membership function is carried out so that it best describes the phenomenon it represents, for which there are no certain rules. In this paper, triangular fuzzy numbers $T = (t_1, t_2, t_3)$, will be used (Figure 1), where t_1 represents left and t_3 right distribution of the confidence interval of the fuzzy number T and t_2 represents the point where the membership function of the fuzzy number has its maximum value, or value 1.

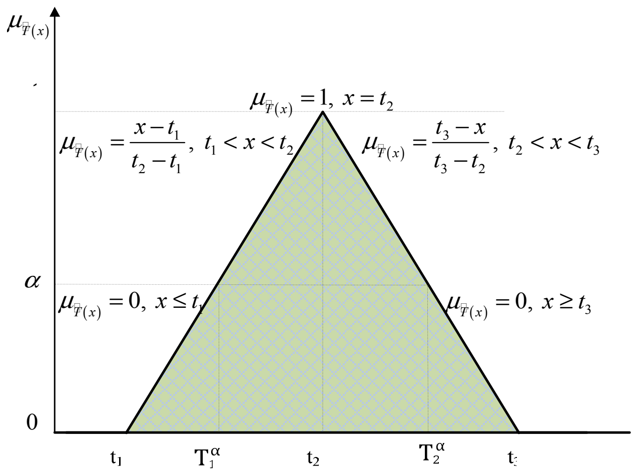

Figure 1 – Triangular fuzzy number T (Pamučar et al., 2016, p.77)
Фигура 1 – Треугольное нечеткое число T (Pamučar i dr., 2016, p.77)
Slika 1 – Trouglasti fuzzy broj T (Pamučar i dr., 2016, p.77)

The elements of fuzzy sets are taken from the confidence interval. The confidence interval contains all the elements that can be considered. Therefore, a fuzzy variable can have only the values from the confidence interval. Determination of the confidence interval of each fuzzy variable is the task of the designer and the most natural solution is to adopt the confidence interval so that it matches the physical limits of the variable (Pamučar, et al., 2016). If the variable is not of physical origin, one of the standard ones is adopted or an abstract confidence interval is defined (Božanić, Pamučar, 2010), (Pamučar, et al., 2011a).

For the purpose of end use, the fuzzy number $T = (t_1, t_2, t_3)$ is converted into a real number. For this operation, a number of methods are used (Herrera Martínez, 2000). Some of the well-known expressions for the defuzzyfication are the following ones (Seiford, 1996)

$$A = ((t_3 - t_1) + (t_2 - t_1)) / 3 + t_1 \tag{2}$$

$$A = \left[\lambda t_3 + t_2 + (1 - \lambda) t_1\right] / 2 \tag{3}$$

where λ is the optimism index, which can be described as the belief/attitude of DM considering the risk in decision making (Milićević, 2014, p.186). The most common optimism index is 0, 0.5 or 1, corresponding to the pessimistic, average and optimistic view of the decision-maker (Milićević, 2014, p.186).

Analytical Hierarchy Process and the Saaty's scale

The AHP method was developed by Thomas L. Saaty. It is based on the decomposition of a complex problem through the hierarchy approach, with the goal at the top, criteria, sub-criteria and alternatives at the levels and sub-levels of the hierarchy (Saaty, 1980), Figure 2.

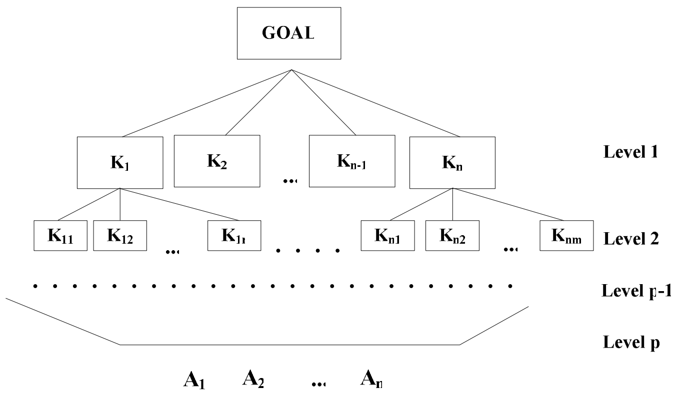

Figure 2 – General hierarchical model in AHP
Фигура 2 – Иерархическая модель AHP
Slika 2 – Hijerarhijski model AHP

The key element of the AHP method is the development of a comparison matrix in pairs. It is made at each level of the hierarchy.

$$A = \begin{array}{c} \\ K_1 \\ K_2 \\ \vdots \\ K_n \end{array} \begin{array}{c} \begin{array}{cccc} K_1 & K_2 & \dots & K_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{12} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \end{array} \tag{4}$$

Pairwise comparison is performed according to the data collected and their measurement, as well as based on own beliefs, estimates or experiences of those who carry out the assessment (Cupic, Suknovic, 2010). A so-called Saaty's scale, Table 1 (Saaty, 1980) is used for pairwise comparison. Since it is true that $a_{ji} = 1/a_{ij}$ and $a_{ii} = 1$ for every $i, j = 1, 2, ..., n$, the matrix A is positive, symmetrical and reciprocal. The essential information on element preferences $E_1, E_2, ..., E_n$ is located only in the upper triangle of the matrix, but all procedures for its further analysis use also the reciprocal values from the lower triangle (Božanić, et al., 2013).

Table 1 – Saaty's scale for a comparison in pairs
Таблица 1 – Шкала Саати для парного сравнения
Tabela 1 – Saaty-jeva skala za poređenje u parovima

Definition	Standard values	Inverse values
The same importance	1	1
Weak dominance	3	1/3
Strong dominance	5	1/5
Very strong dominance	7	1/7
Absolute dominance	9	1/9
Intervalues	2, 4, 6, 8	1/2, 1/4, 1/6, 1/8

The AHP method is outlined in detail in a number of papers. More details can be seen in (Saaty, 1980), (Lootsma, 1988), (Nikolić, Borović, 1996), (Srđević, Srđević, 2004) (Čupič, Suknović, 2010), (Karović, Pušara, 2010), (Devetak, Terzić, 2011), (Inđić, et al., 2014), (Gajović, et al., 2014) and others.

Fuzzyfication of the Saaty's scale

The Saaty's scale, although it is a standard of the AHP, has its drawbacks. It often happens that DM/experts are not entirely sure of the accuracy of comparisons by pairs. Therefore, in the literature, there are an increasing number of papers which in various ways elaborate fuzzyfication of the Saaty's scale (Zhu, et al., 1999), (Srđević, et al., 2008), (Gardaševic-Filipović, Šaletić, 2010), (Pamučar , et al., 2011b), (Božanić, et al., 2013), (Janacković, et al., 2013), (Rezaei, et al. 2014), (Janjić, et al., 2014), (Pamučar, et al., 2015), (Božanić, et al., 2015c) and others. A part of presented fuzzyfications, or scales, is fuzzyficated so that the confidence interval of the membership function is determined prior to research. The second part of papers leaves the possibility that the confidence interval depends on the specific parameters determined in the course of research.

In order to define the weight of criteria, in this paper the fuzzyficated Saaty's scale shown in (Božanić, Pamučar), (Božanić, et al. 2015b) is applied. With this scale, it is defined that DM/experts have a different degree of certainty γ_{ij} in the accuracy of comparisons in pairs they perform. This degree of certainty differs from one to another pair of comparison. The value of the degree of certainty belongs to the interval $\gamma_{ij} \in [0,1]$. In cases where $\gamma_{ij}=0$, it is considered that DM/experts have no data on this relationship, so they should not use it in the decision-making process, because it points to the absolute ignorance of the decision-making matter. The value of the degree of certainty where $\gamma_{ij}=1$ describes the absolute DM/expert certainty in the defined comparison, so, in such cases, a fuzzy number is not used but the standard values of the Saaty's scale. As the certainty in the comparisons lowers, so does γ_{ij}.

Table 2 – Fuzzified Saaty's scale for a comparison in pairs (Božanić, Pamučar), (Božanić, et al. 2015b)
Таблица 2 – Фаззифицированная шкала Саати для парного сравнения (Božanić, Pamučar), (Božanić, et al. 2015b)
Tabela 2 – Fazifikovana Saaty-jeva skala za poređenje u parovima (Božanić, Pamučar), (Božanić, et al. 2015b)

Definition	Standard values	Fuzzy number	Inverse values of fuzzy number
The same importance	*1*	(1, 1, 1)	(1, 1, 1)
Weak dominance	*3*	$\left(3\gamma_{ij}, 3, (2-\gamma_{ij})3\right)$	$\left(1/(2-\gamma_{ij})3, 1/3, 1/3\gamma_{ij}\right)$
Strong dominace	*5*	$\left(5\gamma_{ij}, 5, (2-\gamma_{ij})5\right)$	$\left(1/(2-\gamma_{ij})5, 1/5, 1/5\gamma_{ij}\right)$
Very strong dominance	*7*	$\left(7\gamma_{ij}, 7, (2-\gamma_{ij})7\right)$	$\left(1/(2-\gamma_{ij})7, 1/7, 1/7\gamma_{ij}\right)$
Absolute dominance	*9*	$\left(9\gamma_{ij}, 9, (2-\gamma_{ij})9\right)$	$\left(1/(2-\gamma_{ij})9, 1/9, 1/9\gamma_{ij}\right)$
Intervalues	*2, 4, 6, 8*	$\left(x\gamma_{ij}, x, (2-\gamma_{ij})x\right)$, $x = 2,\ 4,\ 6,\ 8$	$\left(1/(2-\gamma_{ij})x, 1/x, 1/x\gamma_{ij}\right)$ $x = 2,\ 4,\ 6,\ 8$

By defining different values of the parameter γ_{ji}, the left and right distribution of fuzzy numbers change from a comparison to a comparison, according to the expression:

$$T = (t_1, t_2, t_3) = \left\{ \begin{array}{lll} t_1 = \gamma t_2, & t_1 \le t_2, & t_1, t_2 \in [1/9, 9] \\ t_2 = t_2, & & t_2 \in [1/9, 9] \\ t_3 = (2-\gamma) t_2, & t_3 \le t_2, & t_2, t_3 \in [1/9, 9] \end{array} \right\} \qquad (5)$$

t_2 value represents the value of the linguistic expression from the classic Saaty's scale, in which a fuzzy number has its maximum membership $t_2 = 1$.

A fuzzy number $T=(t_1,t_2,t_3)=\left(x\gamma_{ij},x,\left(2-\gamma_{ij}\right)x\right)$, is defined with experessions:

$$t_1=x\gamma_{ij}=\begin{cases}x\gamma_{ij}, \ \forall\ 1\le x\gamma_{ij}\le x\\ 1, \quad \forall\ x\gamma_{ij}<1\end{cases} \tag{6}$$

$$t_2=x,\ \forall\ x\in[1,9] \tag{7}$$

$$t_3=\left(2-\gamma_{ij}\right)x,\forall x\in[1,9] \tag{8}$$

The inverse fuzzy number

$T^{-1}=(1/t_3,1/t_2,1/t_1)=\left(1\big/\left(2-\gamma_{ij}\right)x,1/x,1\big/\gamma_{ij}x\right)$, $x\in[1/9,1)$,

is defined as:

$$1/t_3=1\big/\left(2-\gamma_{ij}\right)x=\begin{cases}1\big/\left(2-\gamma_{ij}\right)x, \ \forall\ x<1\big/\left(2-\gamma_{ij}\right)x<1\\ 1, \ \forall\ 1\big/\left(2-\gamma_{ij}\right)x>1\end{cases} \tag{9}$$

$$1/t_2=1/x,\ \forall\ 1/x\in[1/9,1] \tag{10}$$

$$1/t_1=1\big/\gamma_{ij}x,\forall 1/x\in[1/9,1] \tag{11}$$

On the basis of the previously defined scale, DM/experts fill a new, modified matrix:

$$\begin{array}{cc} & \begin{array}{cccc} K_1 & K_2 & \dots & K_n \end{array} \\ \begin{array}{c} K_1 \\ A=K_2 \\ \vdots \\ K_n \end{array} & \begin{bmatrix} a_{11};\gamma_{11} & a_{12};\gamma_{12} & \dots & a_{1n};\gamma_{1n} \\ a_{21};\gamma_{21} & a_{22};\gamma_{22} & \dots & a_{2n};\gamma_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1};\gamma_{n1} & a_{n2};\gamma_{n2} & \dots & a_{nn};\gamma_{nn} \end{bmatrix} \end{array} \tag{12}$$

A new scale can be applied in group decision-making, which has significantly improved the quality of decision-making. In specific cases, the data collected by the Delphi technique are analyzed separately for each expert. The data analysis is performed by the AIJ synthesis (Aggregating Individual Judgments), where numerical ratings of element preferences are aggregated at the local level (for each matrix separately), in order to obtain a synthetic set of matrices for a fictitious ("group") decision-maker representing the group, and then the standard AHP synthesis could be executed (Zoranović, Srdjević, 2003). After all members of the group have performed the necessary comparisons in pairs of elements of the hierarchy, the filled matrices of type $A(e)=\{a_{ij}(e)\}$ (e = 1, 2, ..., E, where e represents the number of group members), are aggregated into the correspondent unique matrices for the group $A^G = \{a_{ij}^G\}$ by applying, at each position (i,j), a micro aggregation by geometric averaging (Zoranović, Srdjević, 2003) using the formula:

$$a_{ij}^G = \left[\prod_{e=1}^{E} a_{ij}(e) \right]^{1/E} \tag{13}$$

The MABAC method

The MABAC method was developed by Pamučar and Ćirović (2015). The basic setting of the MABAC method is reflected in the definition of the distance of the criterion function of each of the observed alternatives from the approximate border area. The text that follows shows the procedure of implementation of the MABAC method in six steps, i.e. its mathematical formulation:

Step1. Creating the initial decision matrix (X). In the first step, the evaluation of the m alternatives by the n criteria is carried out. The alternatives are presented with vectors $A_i = (x_{i1}, x_{i2}, ..., x_{in})$, where x_{ij} is the value of the i alternative according to the j criteria ($i = 1, 2, ..., m;\ j = 1, 2, ..., n$).

$$X = \begin{array}{c} \\ A_1 \\ A_2 \\ ... \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} K_1 & K_2 & ... & K_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & ... & x_{1n} \\ x_{11} & x_{22} & & x_{2n} \\ ... & ... & ... & ... \\ x_{1m} & x_{2m} & ... & x_{mn} \end{bmatrix} \end{array} \tag{14}$$

where m indicates the number of alternatives, and n indicates the total number of criteria.

Step 2. Normalization of the elements of the initial matrix (X).

$$N = \begin{array}{c} \\ A_1 \\ A_2 \\ ... \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} K_1 & K_2 & ... & K_n \end{array} \\ \begin{bmatrix} t_{11} & t_{12} & ... & t_{1n} \\ t_{11} & t_{22} & & t_{2n} \\ ... & ... & ... & ... \\ t_{1m} & t_{2m} & ... & t_{mn} \end{bmatrix} \end{array} \tag{15}$$

The elements of the normalized matrix (N) are obtained using the following expressions:

a) For the "benefit" type criteria

$$t_{ij} = \frac{x_{ij} - x_i^-}{x_i^+ - x_i^-} \tag{16}$$

b) For the "cost" type criteria

$$t_{ij} = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{17}$$

where x_{ij}, x_i^+ and x_i^- are the components of the initial decision matrix (X), where x_i^+ and x_i^- are defined as:

$x_i^+ = \max(x_1, x_2, ..., x_m)$ and represents the maximum value of the observed criteria by alternatives.

$x_i^- = \min(x_1, x_2, ..., x_m)$ and represents the minimum value of the observed criteria by alternatives.

Step 3. Calculation of the weighted matrix elements (V).

$$V = \begin{bmatrix} v_{11} & v_{12} & ... & v_{1n} \\ v_{21} & v_{22} & ... & v_{2n} \\ ... & ... & ... & ... \\ v_{m1} & v_{m2} & ... & v_{mn} \end{bmatrix} \tag{18}$$

The elements of the weighted matrix (V) are calculated on the basis of expression (19):

$$v_{ij} = w_i \cdot t_{ij} + w_i \tag{19}$$

where t_{ij} are the elements of the normalized matrix (N), and w_i represents the weight coefficient of criteria. By applying the expression (19), we get the weighted matrix V that otherwise can be written as:

$$V = \begin{bmatrix} w_1 \cdot t_{11} + w_1 & w_2 \cdot t_{12} + w_2 & ... & w_n \cdot t_{1n} + w_n \\ w_1 \cdot t_{21} + w_1 & w_2 \cdot t_{22} + w_2 & ... & w_n \cdot t_{2n} + w_n \\ ... & ... & ... & ... \\ w_1 \cdot t_{m1} + w_1 & w_2 \cdot t_{m2} + w_2 & ... & w_n \cdot t_{mn} + w_n \end{bmatrix} \tag{20}$$

where n is the total number of criteria, and m is the total number of alternatives.

Step 4. Determination of the approximate border area (G) matrix. The border approximate area (BAA) for each criterion is determined by expression (21)

$$g_i = \left(\prod_{j=1}^{m} v_{ij} \right)^{1/m} \tag{21}$$

where v_{ij} are the weighted matrix elements (V) and m represents the total number of alternatives.

After determining the value g_i according to the criteria, we form the matrix of approximate border areas G (22) size nx1 (n is the total number of criteria by which the election of the offered alternatives is made).

$$\begin{array}{cccc} K_1 & K_2 & \dots & K_n \end{array}$$
$$G = \begin{bmatrix} g_1 & g_2 & \dots & g_n \end{bmatrix} \tag{22}$$

Step 5. Calculation of the matrix elements distance from the border approximate area (Q)

$$Q = \begin{bmatrix} q_{11} & q_{12} & \dots & q_{1n} \\ q_{21} & q_{22} & & q_{2n} \\ \dots & \dots & \dots & \dots \\ q_{m1} & q_{m2} & \dots & q_{mn} \end{bmatrix} \tag{23}$$

The distance of the alternatives from the border approximate area (q_{ij}) is defined as the difference between the weighted matrix elements (V) and the values of the border approximate areas (G).

$$Q = V - G \tag{24}$$

which otherwise can be written as:

$$Q = \begin{bmatrix} v_{11} - g_1 & v_{12} - g_2 & \dots & v_{1n} - g_n \\ v_{21} - g_1 & v_{22} - g_2 & \dots & v_{2n} - g_n \\ \dots & \dots & \dots & \dots \\ v_{m1} - g_1 & v_{m2} - g_2 & \dots & v_{mn} - g_n \end{bmatrix} \tag{25}$$

where g_i represents the border approximate area for the criterion K_i, v_{ij} is the weighted matrix elements (V), n represents the number of criteria, and m represents the number of alternatives.

The alternative A_i may belong to the border approximate area (G), the upper approximate area (G^+) or the lower approximate area (G^-), respectively $A_i \in \{G \vee G^+ \vee G^-\}$. The upper approximate area (G^+) is an area in which the ideal alternative is found (A^+), while the lower approximate area (G^-) is an area in which the anti-ideal alternative (A^-) is found (Figure 3).

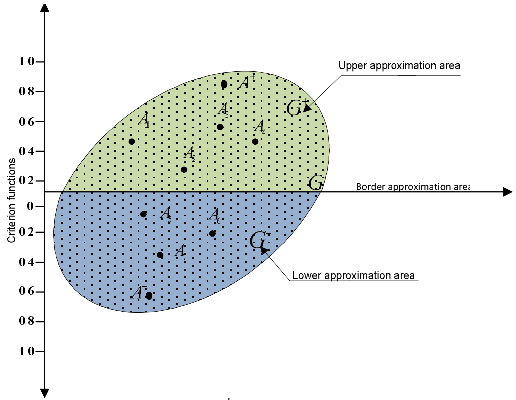

Figure 3 – Presentation of the upper (G^+), lower (G^-) and border (G) approximation areas (Pamučar, Ćirović, 2015)
Фигура 3 – Изображение верхней (G^+), нижней (G^-) и предельной (G) аппроксимативной области (Pamučar, Ćirović, 2015)
Slika 3 – Prikaz gornje (G^+), donje (G^-) i granične (G) aproksimativne oblasti (Pamučar, Ćirović, 2015)

Belonging of the alternative A_i to the approximate area (G, G^+ or G^-) is determined on the basis of expression (26)

$$A_i \in \begin{cases} G^+ \ if \ q_{ij} > 0 \\ G \ if \ q_{ij} = 0 \\ G^- \ if \ q_{ij} < 0 \end{cases} \tag{26}$$

In order for the alternative A_i to be chosen as the best from the set, it is necessary that, according to as many criteria as possible, it belongs to the upper approximate area (G^+). If, for example, the alternative A_i according to 5 criteria (out of 6) belongs to the upper approximate area, and according to one criterion belongs to the lower approximate area (G^-), this means that by 5 criteria the alternative is close or equal to the ideal alternative, while by one criterion it is close or equal to the anti-ideal alternative. The higher the value $g_i \in G^+$, the closer the alternative A_i is to the ideal alternative, while the lower the value $g_i \in G^-$, the closer the alternative A_i is to the anti-ideal alternative.

Step 6. Ranking alternatives. Calculation of criteria function values by alternatives is obtained as the sum of the distances of alternatives from the border approximate areas (q_i). Summing the elements of the matrix Q by rows gives the final values of the criteria function alternatives

$$S_i = \sum_{j=1}^{n} q_{ij},\ j = 1,2,...,n,\ i = 1,2,...,m \tag{27}$$

where n represents the number of criteria, and m represents the number of alternatives

Ranking alternatives - location for the development of laying-up positions by applying the hybrid FAHP-MABAC model

Creating a hierarchical network model represents an important creative stage in the problem solving process, because the consideration of all factors and their interactions is a necessary condition for making a proper solution. Due to the complexity of the problem, the FAHP-MABAC model is proposed as a relevant option of the system analysis and rational decision making when choosing a location for the development of laying-up positions. From a methodological point of view, the proposed FAHP-MABAC model includes two phases, shown in Figure 4.

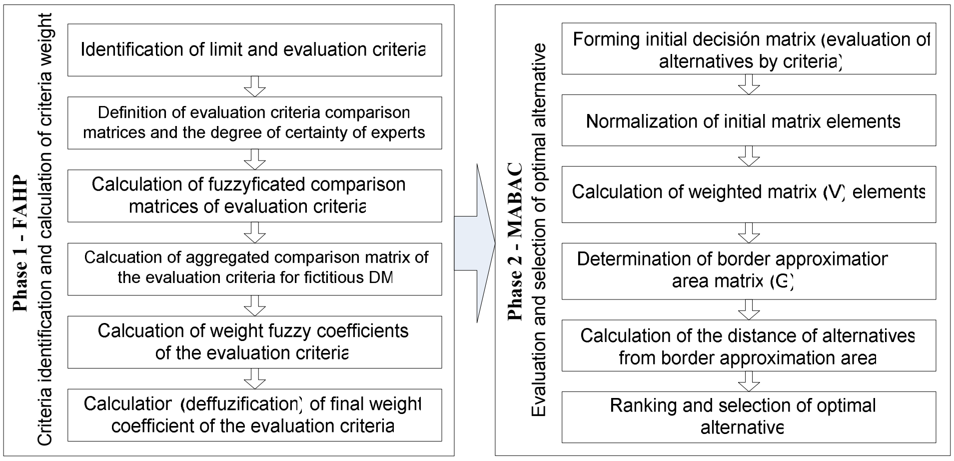

Figure 4 – FAHP-MABAC model
Фигура 4 – Модель FAHP-MABAC
Slika 4 – FAHP-MABAC model

Phase 1 - criteria identification and the calculation of criteria weight coefficients

For the full implementation of the model, it is necessary to define two types of criteria – the limit criteria and the evaluation criteria. In the set of the limit criteria, the criteria are classified on the basis of which the acceptance of specific locations as an alternative is made, or its rejection. After passing through the limit criteria assesment, the alternatives are further ranked using the evaluation criteria. The limit criteria are difficult to define as universal, because they depend on a number of circumstances based on which the decision is made, such as: type of operation, balance of powers, time it takes to create laying-up positions, etc.

In the most general sense, a certain location will not be considered as an alternative in the following situations: when it cannot provide even the minimum conditions for the protection and masking, when it cannot provide even the minimum conditions for the stay of military ships in all meteorological and hydrological conditions, when it is located next to visible objects, when it is not at a sufficient distance from the existing laying-up positions or other protection and masking facilities on the coast and along the coast, when the volume of work is so large that the production can be considered unrewarding, etc.

The evaluation criteria in the selection of the most suitable location for the development of laying-up positions are defined based on the analysis of the available literature. The most detailed description of the conditions which a location for making laying up positions should meet is given in (Milovanović, 1971, pp.169-170). Through a detailed analysis of all conditions, five key evaluation criteria stand out (Milovanović, 1971, pp.169-170), (Božanić et al., 2015a, pp. 695-696):

• C_1 - *masking conditions* - the place where the laying up position is going to be placed should provide a good concealment of military ships, and during masking, as simple mask base as possible should be used (one that can be quickly set and removed);

• C_2 - *scope of work* - a place where production of laying up positions is carried out must ensure the most favorable conditions for its development, ie. as small as possible volume of work, especially when performing underwater works;

• C_3 - *degree of protection* – laying up position should provide the best possible protection from enemy effects from the air, by land or by river;

• C_4 - *benefits for sailing in and out*- approaches to laying-up positions should be safe for quick sailing in and out;

• C_5 - *terrain conditions for the immediate security organization* - the surrounding terrain should provide favorable conditions for possible defense against an imminent attack of a military ship, primarily from sabotage and terrorist groups.

The set of criteria C_i (i = 1, .. 5) consists of two subsets:

• C + - a subset of the "benefit" type criteria, which means that the higher value of the criteria is preferable or better (criteria: C_1, C_3, C_4, C_5), and

• C - a subset of the "cost" type criteria, which means that the lower value is preferable or better (criterion C_2).

The following step is to define a matrix of comparison of the evaluation criteria in pairs and the degree of certainty for each comparison. The matrix is filled by every expert for themselves. In the specific case, the matrix of comparison is provided only for the first expert, Table 3.

Table 3 – Comparison matrix in the pairs of the first expert
Таблица 3 – Матрица парного сравнения первого эксперта
Tabela 3 – Matrica poređenja u parovima prvog eksperta

	C_1	C_2	C_3	C_4	C_5
C_1	1; 1	2; 0.7	2; 0.6	4; 0.9	7; 0.4
C_2	1/2; 0.7	1; 1	2; 0.6	4; 0.8	5; 1
C_3	1/2; 0.6	1/2; 0.6	1; 1	3; 0.7	3; 0.7
C_4	1/4; 0.9	1/4; 0.8	1/3; 0.7	1; 1	2; 0.9
C_5	1/7; 0.4	1/5; 1	1/3; 0.7	1/2; 0.9	1; 1
Inconsistency degree 0.02					

Further follows the calculation of the fuzzyficated matrices of the evaluation criteria based on the expressions set out in Table 2. In the specific case, the fuzzyficated matrix is shown only for the first expert, Table 4.

Table 4 – Comparison matrix in the pairs for the first expert after fuzzyfication
Таблица 4 – Матрица парного сравнения для первого эксперта после фаззификации
Tabela 4 – Matrica poređenja u parovima za prvog eksperta nakon fazifikacije

	C_1	C_2	C_3	C_4	C_5
C_1	1;1;1	1.4;2;2.6	1.2;2;2.8	3.6;4;4.4	2.8;7;11.2
C_2	0.38;0.5;0.71	1;1;1	1.2;2;2.8	3.2;4;4.8	5;5;5
C_3	0.36;0.5;0.83	0.36;0.5;0.83	1;1;1	2.1;3;3.9	2.1;3;3.9
C_4	0.23;0.25;0.28	0.21;0.25;0.31	0.26;0.33;0.48	1;1;1	1.8;2;2.2
C_5	0.09;0.14;0.36	0.2;0.2;0.2	0.26;0.33;0.48	0.45;0.5;0.56	1;1;1

In the following step, the calculation of the aggregated comparison matrix of the evaluation criteria is performed for a fictitious decision maker. The values of all the experts who evaluated the evaluation criteria are aggregated, Table 5.

Table 5 – Comparison matrix in the pairs after the aggregation of experts' matrices
Таблица 5 – Матрица парного сравнения после агрегации матриц экспертов
Tabela 5 – Matrica poređenja u parovima nakon agregacije matrica eksperata

	C_1	C_2	C_3	C_4	C_5
C_1	1;1;1	2.02;2.21;2.36	1.17;1.5;1.86	2.97;3.72;4.46	3.2;5.86;8.28
C_2	0.42;0.45;0.49	1;1;1	0.67;0.93;1.2	2.75;4.23;5.56	3;3.87;4.46
C_3	0.54;0.67;0.86	0.84;1.07;1.49	1;1;1	2.3;3.46;4.57	3.87;4.58;5.26
C_4	0.22;0.27;0.34	0.18;0.24;0.36	0.22;0.29;0.43	1;1;1	2.6;3.56;4.41
C_5	0.12;0.17;0.31	0.22;0.26;0.33	0.19;0.22;0.26	0.23;0.28;0.39	1;1;1

Based on the data from Table 5, with the standard steps of the AHP method, the calculation of the weight coefficients of the evaluation criteria is carried out. The resulting weight coefficients of the criteria are presented in Table 6. The label "l" represents the left distribution of the fuzzy number; "d" represents the right distribution of the fuzzy number and "s" - a place where the level of the membership of the fuzzy number has a value one.

Table 6 – Fuzzy weight coefficients of the evaluation criteria
Таблица 6 – Нечеткие весовые коэффициенты критериев оценки
Tabela 6 – Fuzzy težinski koeficijenti kriterijuma evaluacije

	(l)	(s)	(d)
C_1	0.364	0.387	0.357
C_2	0.228	0.216	0.227
C_3	0.254	0.239	0.255
C_4	0.101	0.102	0.104
C_5	0.052	0.057	0.057

In the end, by the application of expression (2), the defuzzyfication of the weight coefficients of the evaluation criteria is performed. The final values of the weight coeficients of the criteria are given in Table 7.

Table 7 – Final values of the weight coefficients
Таблица 7 – Конечные значения весовых коэффициентов
Tabela 7 – Konačne vrednosti težinskih koeficijenata

	Weight coeficients of the criteria
C_1	0.370
C_2	0.224
C_3	0.249
C_4	0.102
C_5	0.055

Phase 2 - evaluation and selection of the optimal alternative

Through the second phase, the evaluation and ranking of alternatives is performed by the application of the MABAC method. The first step in the implementation of the method is to define the initial decision matrix. Since the evaluation criteria have a qualitative character, for the evaluation of alternatives by all criteria, the fuzzyficated Likert scale was used (Campari, 2013), Table 8.

Table 8 – Fuzzyfied Likert scale for the evaluation of alternatives
Таблица 8 – Фаззифицированная шкала Лайкерта для оценки альтернатив
Tabela 8 – Fazifikovana Likertova skala za evaluaciju alternativa

Linguistic description for „benefit“ type criteria	Triangular fuzzy number	Linguistic description for „cost“ type criteria
very good	(4.5;5;5)	Very small
good	(3.5;4;4.5)	small
medium	(2.5;3;3.5)	medium
bad	(1.5;2;2.5)	big
very bad	(1;1;1)	Very big

In the specific case, the fuzzyficated Likert scale is applied to provide the assessment of ten illustrative alternatives, whose values are defuzzyficated by using expression (2) and shown in Table 9.

Table 9 – Initial decision matrix (X)
Таблица 9 – Исходная матрица принятия решений (X)
Tabela 9 – Početna matrica odlučivanja (X)

	C_1	C_2	C_3	C_4	C_5
A_1	4.83	1	4	2	1
A_2	4	2	4.83	1	3
A_3	2	4	1	4.83	2
A_4	3	3	4.83	2	4
A_5	1	2	2	3	4.83
A_6	3	4.83	1	4	3
A_7	4	3	3	4	4.83
A_8	4.83	1	2	3	1
A_9	1	4.83	4	1	4
A_{10}	3	4	3	4.83	2

The next step is the normalization of the initial matrix elements by the application of expressions (16) and (17). The normalized matrix (N) is presented in Table 10.

Table 10 – Normalized matrix (N)
Таблица 10 – Нормированная матрица (N)
Tabela 10 – Normalizovana matrica (*N*)

	C_1	C_2	C_3	C_4	C_5
A_1	1.00	1.00	0.78	0.26	0.00
A_2	0.78	0.74	1.00	0.00	0.52
A_3	0.26	0.22	0.00	1.00	0.26
A_4	0.52	0.48	1.00	0.26	0.78
A_5	0.00	0.74	0.26	0.52	1.00
A_6	0.52	0.00	0.00	0.78	0.52
A_7	0.78	0.48	0.52	0.78	1.00
A_8	1.00	1.00	0.26	0.52	0.00
A_9	0.00	0.00	0.78	0.00	0.78
A_{10}	0.52	0.22	0.52	1.00	0.26

The weighted matrix (V) is calculated using expression (19), Table 11.

Table 11 – Weighted matrix (V)
Таблица 11 – Нечеткая матрица (V)
Tabela 11 – Otežana matrica (*V*)

	C_1	C_2	C_3	C_4	C_5
A_1	0.74	0.45	0.44	0.13	0.06
A_2	0.66	0.39	0.50	0.10	0.08
A_3	0.47	0.27	0.25	0.20	0.07
A_4	0.56	0.33	0.50	0.13	0.10
A_5	0.37	0.39	0.31	0.16	0.11
A_6	0.56	0.22	0.25	0.18	0.08
A_7	0.66	0.33	0.38	0.18	0.11
A_8	0.74	0.45	0.31	0.16	0.06
A_9	0.37	0.22	0.44	0.10	0.10
A_{10}	0.56	0.27	0.38	0.20	0.07

Then the approximate border areas are calculated using expression (21), Table 12.

Table 12 – Border approximation area matrix (G)
Таблица 12 – Матрица предельных аппроксимативных областей (*G*)
Tabela 12 – Matrica graničnih aproksimativnih oblasti (*G*)

	C_1	C_2	C_3	C_4	C_5
GAO	0.55	0.32	0.37	0.15	0.08

The penultimate step is the calculation of the distance of alternatives from the border approximate area by the application of expression (24), Table 13.

Table 13 – Distance of the alternative from the border approximation area
Таблица 13 – Расстояние альтернатив от предельных аппроксимативных областей
Tabela 13 – Udaljenost alternativa od graničnih aproksimativnih oblasti

	C_1	C_2	C_3	C_4	C_5
A_1	0.19	0.12	0.08	-0.02	-0.03
A_2	0.11	0.07	0.13	-0.05	0.00
A_3	-0.09	-0.05	-0.12	0.05	-0.01
A_4	0.01	0.01	0.13	-0.02	0.02
A_5	-0.18	0.07	-0.05	0.01	0.03
A_6	0.01	-0.10	-0.12	0.03	0.00
A_7	0.11	0.01	0.01	0.03	0.03
A_8	0.19	0.12	-0.05	0.01	-0.03
A_9	-0.18	-0.10	0.08	-0.05	0.02
A_{10}	0.01	-0.05	0.01	0.05	-0.01

In the end, expression (27) is applied for ranking the alternatives, Table 14.

Table 14 – Rank of the alternatives
Таблица 14 – Рейтинг альтернатив
Tabela 14 – Rang alternativa

	Si	Rank
A_1	0.342	1.
A_2	0.259	2.
A_3	-0.212	9.
A_4	0.145	5.
A_5	-0.135	7.
A_6	-0.172	8.
A_7	0.188	4.
A_8	0.239	3.
A_9	-0.236	10.
A_{10}	0.014	6.

Based on the obtained values Si, the alternatives are ranked from the most suitable alternative (A_1) to the most unfavorable one (A_9).

Sensitivity analysis of the output results

A logical sequence in most multi criteria decision-making processes is to analyze sensitivity. It is recommended as a means of checking the stability of the results against the subjectivity of decision-makers (Meszaros, Rapcsak, 1996). The sensitivity analysis of the results is carried out by changing the initial weight coefficients of the evaluation criteria. The situations of changing weight coefficients, from A to F, are provided in Table 15.

Table 15 – Scenarios with different weights of the criteria
Таблица 15 – Сценарий изменения веса критерия
Tabela 15 – Scenariji promene težina kriterijuma

	A	B	C	D	E	F
K_1	0.2	0.6	0.1	0.1	0.1	0.1
K_2	0.2	0.1	0.6	0.1	0.1	0.1
K_3	0.2	0.1	0.1	0.6	0.1	0.1
K_4	0.2	0.1	0.1	0.1	0.6	0.1
K_5	0.2	0.1	0.1	0.1	0.1	0.6

Ranks of alternatives using different situations are given in Table 16.

Table 16 – Ranks of alternatives by the application of different situations
Таблица 16 – Рейтинги альтернатив при применении различных сценариев
Tabela 16 – Rangovi alternativa primenom različitih scenarija

	Rank from Table 14	A	B	C	D	E	F
A_1	1	2	1	1	3	7	8
A_2	2	2	4	3	1	9	4
A_3	9	9	8	8	10	3	10
A_4	5	2	5	6	1	7	3
A_5	7	7	8	5	8	6	2
A_6	8	8	7	9	9	5	6
A_7	4	1	2	4	4	1	1
A_8	3	5	3	2	7	4	9
A_9	10	10	10	10	6	10	5
A_{10}	6	6	6	7	5	2	7

Table 16 shows a significant result stability compared to situations A, B, C and slightly less D (especially when it comes to the first five alternatives). The stability of the results compared to situations E and F is much smaller, which could be expected if we bear in mind that the importance of the favored criteria in the developed model is several times smaller.

Conclusion

The review of a practical application of the FAHP-MABAC model and its sensitivity analysis indicate the potential of the application of the created models in real situations. Based on the already-made hybrid model, the proposed alternatives are successfully ranked.

The hybrid model uses the advantages of several methods. The first one is the fuzzyficated Saaty's scale, which has been used for obtaining the weight of criteria functions, which successfully covered the uncertainty of experts in claims based on paired comparison.

Also, the new MABAC method is shown as well as its successful implementation in practice. The analysis of the output results sensitivity has shown that the hybrid FAHP-MABAC model provides stable solutions to the problem of choice of laying-up positions. The model is applicable in the process of operational planning for different situations and provides reliable solutions.

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ГИБРИДНАЯ МОДЕЛЬ FUZZY AHP (FUZZY ANALYTICAL HIERARCHY PROCESS) МЕТОДА АНАЛИТИЧЕСКОЙ ИЕРАРХИИ В НЕЧЕТКИХ УСЛОВИЯХ – MABAC (MULTI-ATTRIBUTIVE BORDER APPROXIMATION AREA COMPARISON) ДЛЯ РАНЖИРОВАНИЯ ПОТЕНЦИАЛЬНЫХ ПОЗИЦИЙ УСТРОЙСТВА ЗАМАСКИРОВАННЫХ ПРИЧАЛОВ

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Резюме:

В работе представлена гибридная модель FAHP-MABAC. Фаззифицированная шкала Саати с методом AHP (FAHP) применяется для определения весовых коэффициентов критериев. Метод MABAC применяется в процессе оценки и ранжирования альтернатив. Гибридная модель разработана для поддержки принятия решений при выборе позиций для устройства замаскированных причалов (объекты, предназначенные для скрытия, защиты и маневров боевых кораблей).

Ключевые слова: *выбор позици, fuzzy AHP, MABAC.*

HIBRIDNI MODEL FUZZY AHP-MABAC ZA RANGIRANJE POTENCIJALNIH LOKACIJA ZA IZRADU MASKIRNIH VEZOVA

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OBLAST: matematika, operaciona istraživanja
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Sažetak:

U radu je predložen hibridni model FAHP-MABAC. Fazifikovana Saaty-jeva skala sa metodom AHP (FAHP) primenjuje se za definisanje težinskih koeficijenata kriterijuma. Metoda MABAC primenjena je u procesu evaluacije i rangiranja alternativa. Hibridni model razvijen je za podršku odlučivanju pri izboru lokacija za izradu maskirnih vezova (objekti namenjeni za prikrivanje, zaštitu i manevar vojnih brodova).

Uvod

U ovom radu prikazan je hibridni model korišćenjem fazifikovane Saaty-jeve skale i metode analitičkog hijerarhijskog procesa (FAHP) i metode MABAC (Multi-Attributive Border Approximation area Comparison) – model FAHP-MABAC. U radu su ukratko opisane metode koje se primenjuju, sa detaljnijom razradom fazifikacije Saaty-jeve skale i metode MABAC. Hibridni model FAHP-MABAC izrađen je za podršku odlučivanju prilikom izbora lokacija za izradu maskirnih vezova.

U delu pod nazivom Opis metoda koje se primenjuju u hibridnom modelu FAHP-MABAC opisane su primenjene metode kroz nekoliko podnaslova:

U tekstu pod naslovom Fuzzy logika i fuzzy skupovi ukratko je izvršeno definisanje fuzzy skupa, izbor oblika funkcije pripadnosti i intervala poverenja.

U tekstu pod naslovom Analitički hijerarhijski proces i Saaty-jeva skala ukratko su predstavljene osnove analitičkog hijerarhijskog procesa i prikazana klasična Saaty-jeva skala.

Fazifikacija Saaty-jeve skale

U literaturi se može pronaći veliki broj fazifikacija Saaty-jeve skale. Fazifikacija se najčešće vrši tako što se umesto stepena poređenja definišu fuzzy brojevi sa unapred definisanim intervalima poverenja. Osnovna ideja fazifikacije Saaty-jeve skale u ovom radu jeste da intervali poverenja budu definisani nakon završenog poređenja u parovima od strane donosilaca odluke –eksperata. Stoga je definisano da je interval poverenja svakog fuzzy broja, koji definiše stepen poređenja, povezan sa stepenom uverenosti donosilaca odluka – eksperata u datu tvrdnju. Drugim rečima, interval poverenja proračunava se na osnovu stepena uverenosti donosilaca odluka γ_{ji}, *a prema tabeli 2.*

Metoda MABAC

U ovoj celini prikazani su standardni koraci metode MABAC: 1) formiranje početne matrice odlučivanja (X), 2) normalizacija elemenata početne matrice, 3) proračun elemenata otežane matrice (V), 4) određivanje matrice graničnih aproksimativnih oblasti (G), 5) proračun elemenata matrice udaljenosti alternativa od granične aproksimativne oblasti (Q) i 6) rangiranje alternativa.

Rangiranje alternativa – lokacija za izradu maskirnih vezova primenom hibridnog modela FAHP-MABAC

U ovoj celini prikazana je praktična primena hibridnog modela FAHP-MABAC. Prikaz primene izvršen je kroz dve faze.U prvoj fazi identifikovani su kriterijumi i proračunati težinski koeficijenti kriterijuma. Po identifikovanim kriterijumima vrši se ocena alternativa. Identifikovano je pet kriterijuma (uslovi maskiranja, obim radova, stepen zaštite, povoljnost za uplovljavanje i isplovljavanje i uslovi terena za organizaciju neposrednog obezbeđenja) i definisani njihovi težinski koeficijenti (

tabela 7).U drugoj fazi izvršena je evaluacija i izbor optimalne alternative. Rangirane su ocene i deset alternativa.

Analiza osetljivosti rezultata sprovedena je promenom početnih težinskih koeficijenata kriterijuma evaluacije. Takođe, pokazala je stabilnost rezultata u odnosu na veći broj scenarija.

Hibridnim modelom FAHP-MABAC uspešno je izvršena evaluacija i rangiranje predloženih alternativa.

Ključne reči: *izbor lokacije, fuzzy AHP, MABAC.*

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AUTOMATION OF RIDE ORDERS FOR PASSENGER VEHICLES

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Abstract:

Effective functioning of organizations depends on the quality of management of interconnected and interdependent business processes. The key problem in the projects implementation is associated with ignorance of business processes of a business itself. The paper provides an approach for modeling business processes through a selection of tried and tested methods and models for coping with the complexity of systems. Business high-level features are decomposed into smaller functional units, resulting in a hierarchical structure of business functions of different granularity. At the bottom of the functional decomposition hierarchy, there are so-called primitive functions which are in fact managing processes. The specifications of the interactions between the systems participants are use case diagrams. The specification of business processes has been realized through BPMN diagrams (choreographies and collaboration diagrams). An automated solution improves the quality of operations and coordinates all participants in this business system. In this paper, the business analysis method has been presented as well as the results of the design of the segment called "a ride order for passenger vehicles" and the business processes closely associated with it.

Key words: *company car, ride order, vehicle, BPMN, UMM, BPM, business process management systems, business process.*

Introduction

The task of a business analysis is to define a quality method to recognize business needs, to define requirements and design solutions to meet the set requirements necessary to solve business needs.

A key problem in all implementation projects of any solutions for any organization is associated with the ignorance of business processes of the organization itself (Aničin, Pantović, 2014). This ignorance does not only concern the implementer's team headed by the project manager, but it is also related to employees who need to instruct the implementer's team how the business process functions and what their real needs are (Aničin, Pantović, 2014).

Existing software solutions in this area are mostly realized on outdated software platforms, without a necessary analysis and applying the methodology of information systems. Also, most of the existing solutions do not possess software documentation, making it difficult to maintain them.

The main goal of this paper is to present a method of business analysis and the results of applying the methodology of the implementation tool Access / SQL server. It elaborates in particu ar the design results in the segment of ride orders for passenger vehicles and closely related business processes.

The paper provides an approach for modeling business processes through a selection of tried and tested methods and models for dealing with the complexity of the system.

In order to obtain a holistic view of the problem of managing interdependent business processes in a complex system, let us first explain the systems for managing business processes (Business Process Management - BPM). Business Process Management aims to improve operational business processes, possibly without the use of new technologies. Below are the definitions of modeling business processes, followed by an approach for modeling business processes. This paper presents a choice of methods and models for dealing with the complexity of the system. The application of the proposed methods and models is illustrated by a decomposition of business processes and a detailed specification of the business process of the ride order for passenger vehicles. The next chapter provides the specification of the business process management of the ride order through BPMN (Business Process Model and Notation) diagrams.

The following chapter lists the results for the system design VozIS - screen forms application. The final chapter gives the conclusion that outlines the main contribution of this work and plans for future work.

Methodology

BPM is a system and a platform for connecting architecture organization, models of business processes, systems management workflow and information infrastructure to support execution of business processes.

A modern BPM system allows users to model the analysis and simulation processes, transform models into the program code, integrate with business applications, perform process control and monitoring workflows, optimize business processes, increase customer satisfaction, reduce inefficiencies, and analyze the performance of business processes after performing (Weske, 2007).

BPM must be deeply embedded in the organizational structure and it requires a professional and efficient approach to the management process as well as the involvement of all relevant target groups.

Figure 1 – Business Process Management
Рис. 1 – Управление бизнес-процессами
Slika 1 – Upravljanje poslovnim procesima

It can be seen (Figure 1) that business process management results in real-time processing, generating internal and external reports as well as in realized increased productivity and information control. Management is based on the management of roles, implemented process optimization, reducing inefficiency which leads to increased customer satisfaction.

Models are simplified real-world performances, such as models of airplanes, building plans, and database schemas.

Models are presented in a language (language modeling) which can be a textual notation (models in the text format) and a graphic notation (models in the form of diagrams). Modeling business processes means a consistent application of graphic methods and appropriate software tools to show the reliability of business processes, but also a concrete way of their performance (Tumbas, 2006).

Business functions of higher levels can be decomposed into smaller functional units, resulting in a hierarchical structure of business functions of different granularity. At the bottom of the functional decomposition hierarchy there are so-called “primitive functions“ (Lazarevic et al., 2006), which are in factexecutive processes.The process of breaking up a large fraction of functions into fine (smaller) granularity is traditionally called functional decomposition.

This paper uses the UN / CEFACT (United Nations Centre for Trade Facilitation and Electronic Business) Modeling Methodology (UMM), which is normally used in modeling business processes in e-business.

The UML package is a general mechanism for grouping any elements in the group, and, through it, for performing a decomposition of functional domains and complex processes. It has various levels of decomposition for specifically defined, specific stereotypes of business processes. The entire model is presented as package <<Business Domain>> (still in operation <<b Domain>>, which is an aggregation of all sub-processes. <<b Domain>> is decomposed so that it can contain one or more types of complex sub-processes <<Business Area>> (<<b Area>>) and <<process Area>>, or a primitive type process <<Business Process>> (<<b Process UC>>). One process stereotype <<b Area>> can be decomposed to one or more complex processes stereotypes <<process Area>> or a primitive process stereotype <<b Process UC>> (Lazarević, et al., 2006).

A primitive business process can be presented through a Unified Modeling Language (UML) diagram of a use case to define the specification of the interactions between the system actors (participants), together with a description of the system actions in this interaction.

The methods and models are applied to illustrate the decomposition of business processes of organization, with a detailed specification of the business process management system for a vehicle management system.

The process is any activity or group of activities that takes an input, adds value to it and provides an output to any internal or external customers. Business processes use organizational resources to accomplish planned results (Harrington’s, 1991). There are different types of business processes: (Tumbas, 2006)

- Operational processes - production, purchase, sale,
- Support processes - maintenance, accounting, IT support,
- Control processes - planning, control.

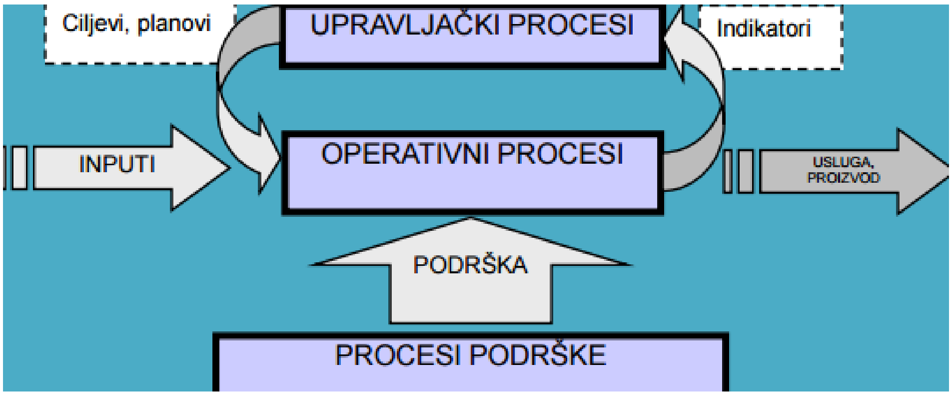


Figure 2 – Different types of business processes
Рис. 2 – Различные типы бизнес-процессов
Slika 2 – Različite vrste poslovnih procesa

Business processes are the "heart" of an organization and the entire business of an organizational system (e. g the organization) is done through business processes.

The model shown represents the current state of the process, which can be improved in future versions. The model is dynamic, due to the related processes with other organizational systems in order to optimize operations.

An existing business process can be innovated (Business Process Improvement), or fundamentally improved (Business Process Reengineering).

To create the project, the standards for functional modeling IDEF0, realized through the BPwin CASE tool, were also used. (IDEF0 Standard, www.idef.com).The IDEF0 is a modeling technique based on a combination of graphics and text presented in an organized and systematic manner in order to increase user-friendliness and provide logic for potential changes and specified requirements, ie. to support the analysis of the system according to the levels (Veljović, 2002).

The activity tree shown in Figure 3 represents a strategic decision of the company management and is not an organizational chart. To abandon the "organizational" approach and adopt the process approach, it is necessary to imagine that only one person performs all tasks in the organization.

Jobs at the top (root) are always marked with 0. The numbers are used to show how much detail a job contains. Business A0 is decomposed (separated) to 1, 2, 3, etc. Job 1 is composed of 11, 12, 13, etc. A higher-level job is called a “parent”, and subordinate jobs are “children”.

The activity decomposition of parents to their children should have 3 to 6 subordinate activities. More than six out of a certain activity is an attempt to fit too much detail into one level.

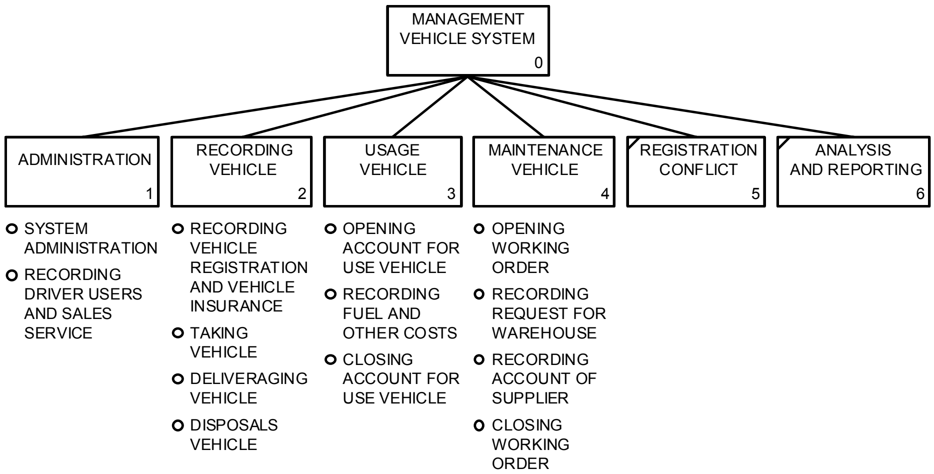


Figure 3 – Activity tree
Рис. 3 – Ветви деятельности
Slika 3 – Stablo poslova

This approach makes it easy to connect with the future development of an integrated IS and it meets the requirements of ISO 9000 quality management system.

In the phase of the system functional decomposition, there were used decomposition diagrams that show the place / position of abusiness process in the organizational structure of the organization, as well as guidance and examples for the design of business processes and systems for a vehicle management system(van der Aalst, 2013).

The decomposition of functional domains and a complex process of <<Business Domain>> to primitive process stereotype <<b Process UC>> is described in the paper (Terzić, 2015). In this paper, theprocess area vehicle management systemis presented in Figure 4.

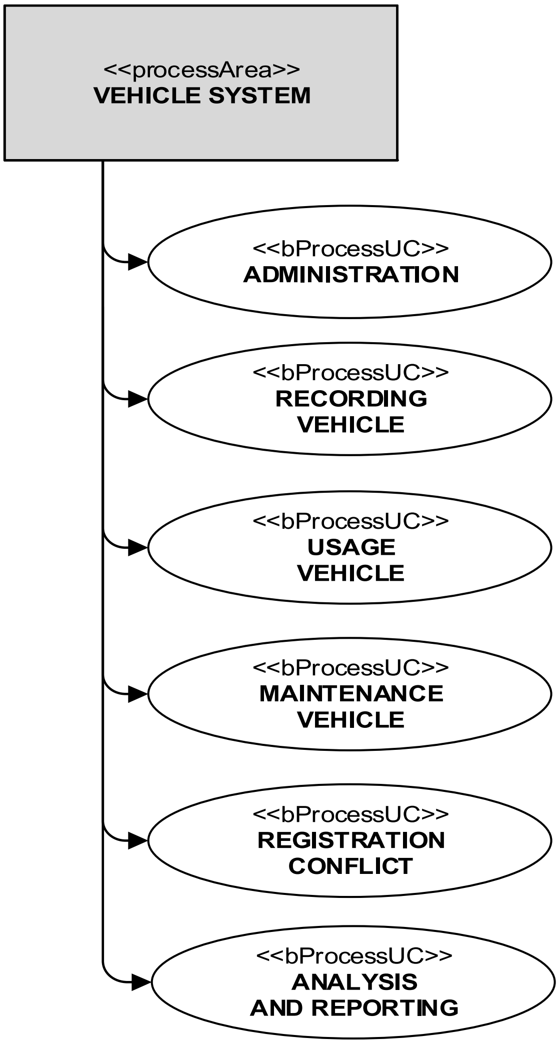


Figure 4 – Process Area – company vehicle
Рис. 4 – Процессная область – служебный автомобиль
Slika 4 – Procesno područje – službeno vozilo

A primitive business process can be performed using the *Unified Modeling Language* (UML) diagram of a use case to define the specification of interactions between the system actors (participants), together with a description of actions in this system interaction. The Use Case diagram is shown in Figure 5.

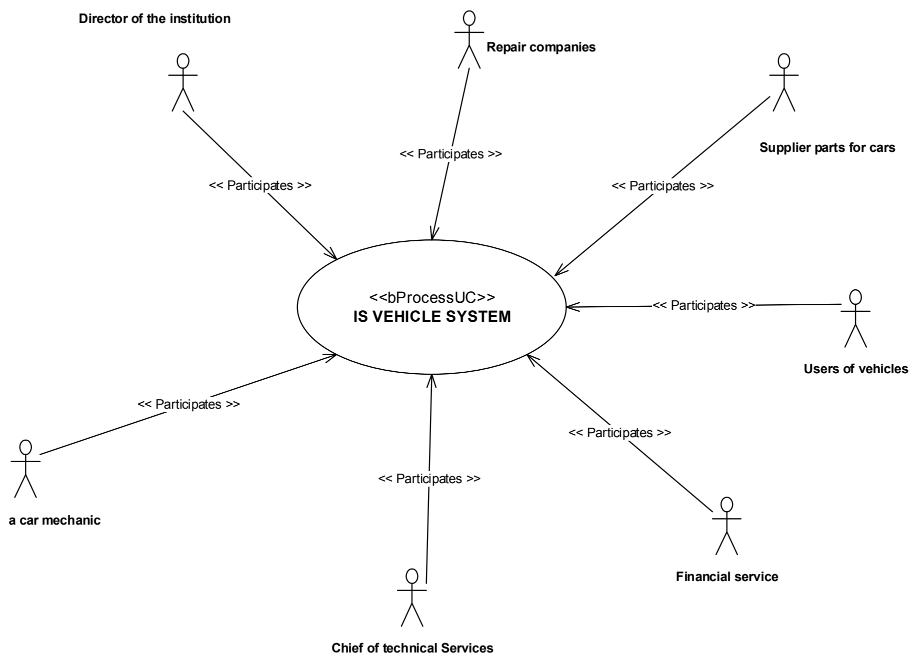


Figure 5 – Use Case Diagram
Рис. 5 – Диаграмма прецедентов
Slika 5 – Dijagram slučaja korišćenja

The Use Case diagram (Figure 5) shows the business process and all the actors / participants in the business process VP.

After performing the functional decomposition of the system and the global description of the primitive process through the model use cases, it is necessary to identify business processes precisely, in detail and possibly to formalize the min order to allow the automation and execution of the system for business process management.

Specifications of business processes are implemented into BPMN (Business Process Model and Notation) diagrams.

A graphic-oriented language was used here for modeling business processes BPMN 2.0 (Allweyer, 2010) and (OMG 2010) and (OMG 2011).

Version 2.0 BPMN modeling language business process has a very rich set of concepts and provides several different types of diagrams for expressions of choreography and orchestration at different levels of abstraction.

BPMN has “elementary and complex concepts for modeling business processes”. BPMN elementary concepts can be classified into one of the following five basic categories (Nešković, Petrović, 2009) Flow Objects, Connection Objects, Swim Lanes, Data Objects, and Artifacts. From these elementary concepts, complex concepts can be built: Orchestration, Collaboration, Choreography and Conversation.

BPMN diagramming of the ride order management process

For the purpose of this article, the business process management of a ride order is described in detail.

A flowchart / Collaboration (Figure 6) is used to display orchestration because the dates of BPMN 2.0 process orchestration means the activities it is composed of. This type of standard diagrams contains the flow of objects (activities, events and dates) that are associated with the flow of sequences. Collaboration describes the interaction between two or more business entities. It usually contains two or more partitions (pools).

Actors / participants in this context are the user of the vehicle, an administrative worker, the Head of the Vehicles System, a car mechanic and a central warehouse operator.

The ride order business management process starts when a customer comes into the Vehicle Technical Service with a request to use a vehicle. The vehicle user first makes a request to use a vehicle. After checking the roadworthiness of vehicles and their availability, the process continues.

An administrative worker records the received request and forwards the request to the Head of the Vehicles System. Depending on the technical validity / availability of the vehicles system, the Head approves or refuses the vehicle use.

In the event that a technical defect on the vehicle is detected, or that a vehicle has already been in the process of defect detection, parts are required from the central storage and the fault is repaired. Upon completion of this process, the Head of the Vehicles System or the Head of the Technical Service is informed that the vehicle is repaired and ready for use.

In the event that the request for the use of vehicles is refused, the user is notified about it.

If the request for the vehicle use is approved, a ride order is created and the further use of the vehicle is monitored.

During the use of company vehicles, fuel costs and repair costs can occur due to malfunction or damage to the vehicle. In both cases, upon returning to the organization, the bills of incurred costs during the use are submitted.

At the end of the process of using a company vehicle, the vehicle is parked in a parking lot, the keys are handed over, the ride order for that particular passenger vehicle is completed as well as any proofs of costs if they have occurred during the use of the vehicle and the vehicle parking place is recorded.

The last stage in the process of managing a ride order is to update the database and change the status of the vehicle at leisure for the next usage.

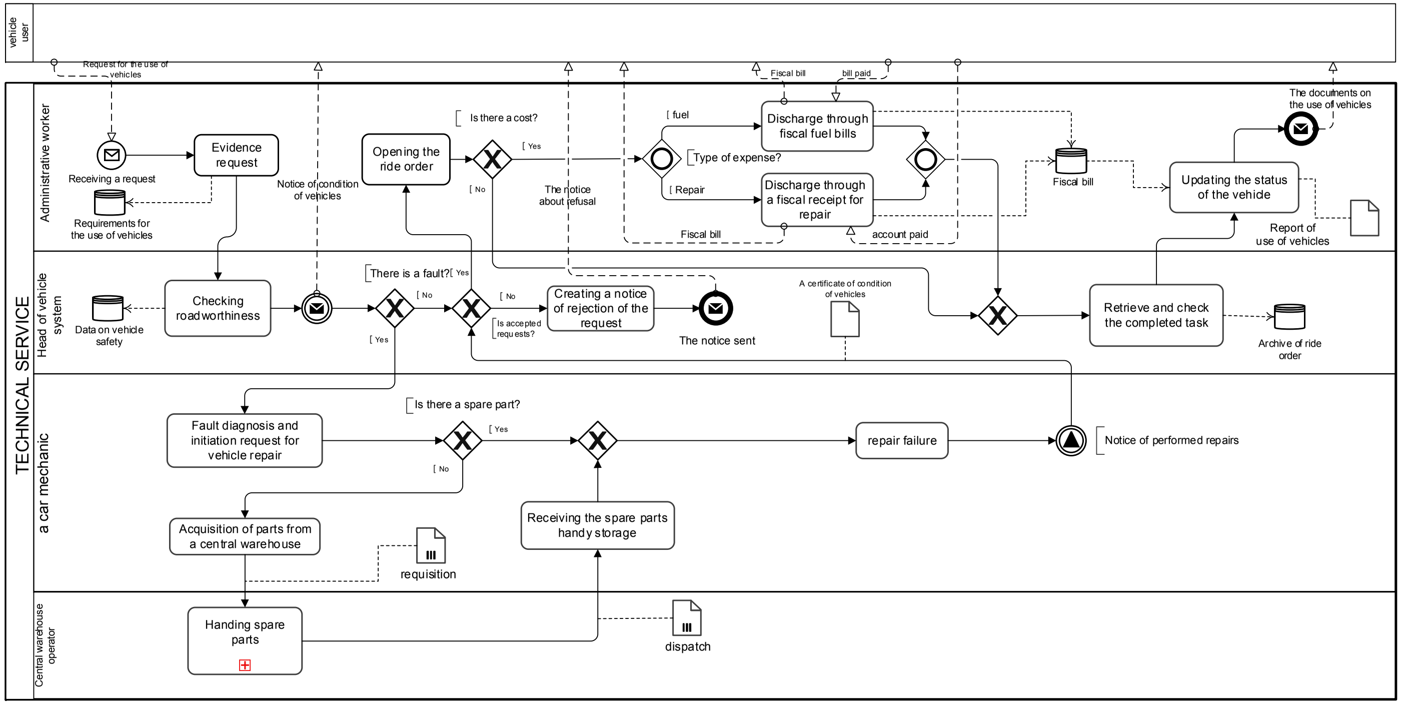


Figure 6 – Collaborative process diagram for a ride order for passenger vehicles
Рис. 6 – Диаграмма кооперации для процесса: Путевой лист для легковых автомобилей
Slika 6 – Kolaboracioni dijagram za proces putni nalog za putnička vozila

Choreography (Figure 7) observes the process through a set of messages exchanged between the participants. It defines the expected behavior among participants. Unlike internal processes that exist within a single partition (pool), choreography exists between partitions (pools) and participants. We will define the sequence of messages which are exchanged.

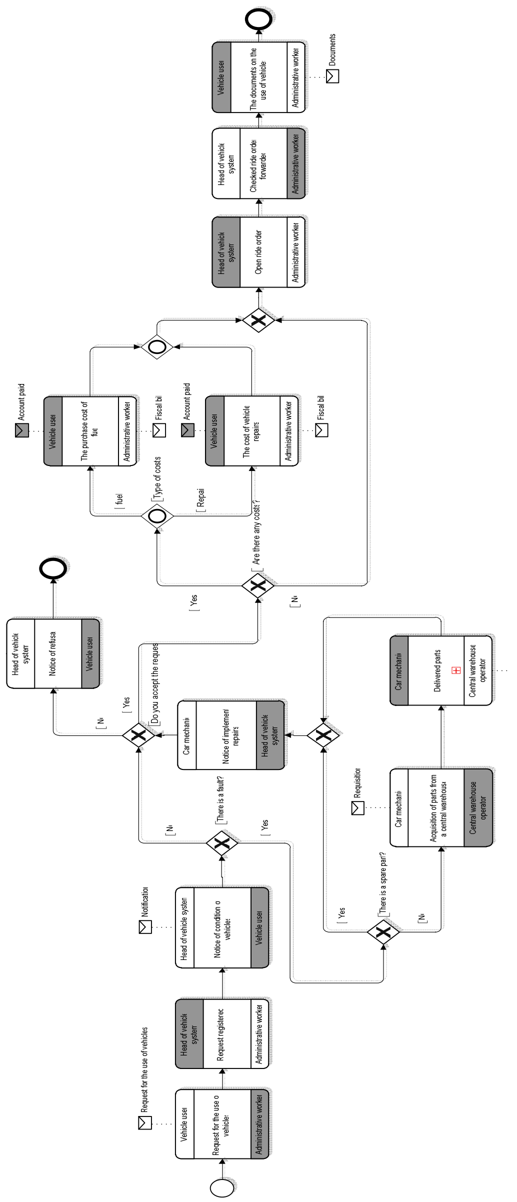


Figure 7 – Choreography diagram
Рис. 7 – Схема *хореографии*
Slika 7 – Dijagram koreografije

The first message in this process is a request for the use of the vehicle. That request is forwarded to the chief administrative officer (the Head) of the Vehicles System. On the basis of the vehicle operational state and availability check, the subsequent messages are generated.

If the vehicle has a defect, an order for the fault removal is written. Upon the failure detection, if a spare part for the vehicle repair is needed, a mechanic fills in an order for a requisition / purchase of the particular spare part(s).

When purchasing the required spare part, the operator dispatches the required part through the central warehouse. After the vehicle repair, a car mechanic sends a certificate of roadworthiness for the vehicle.

Defect-free vehicles are taken on the basis of an open ride order.

During the use of company vehicles, additional costs may occur. These are the costs for repairs of unplanned failures and the costs for filling up the tank.

Upon completion of the use of the vehicle, the handover is completed with the bills of costs incurred during the use of the vehicle as well as the vehicle keys.

If you do not approve the use of the vehicle, the vehicle user receives a negative response.

Design results

The VozIS information system is used for recording data on the use of vehicles, recorded registration processes, servicing, ride orders for passenger vehicles, costs related to vehicle fuel consumption and system created / produced documents - reports based on ISO standards (e.g. Receipt form).

Data is entered when necessary. All the required information on individual vehicles can be recorded in a very simple and clear way.

The program itself informs the user when it is time for the registration service, the predefined number of days or the number of kilometers in advance. It is possible to record an unlimited number of vehicles, vehicle data, periodic maintenance, driving and vehicle operating costs. The program includes a full set of supporting records in which the data is sufficient to be defined only once, and then any number of times entered in the register simply by selecting from the drop-down list. Therefore, entering data into the program is simplified and fast, while a manual entry of the same data is completely eliminated.

At any time, entered data can be viewed, changed, print or sent by e-mail. The program generates a lot of useful reports and is suitable for the planning of future expenditure and a number of reports such as:

-View all costs within a certain time interval for all or a specific vehicle. This refers to services, registration, fuel and other costs.

- Only the cost price per day for one or more vehicles.
- Only the cost per driver or all the drivers.
- Control and supervision of the finance concerning fuel, maintenance and other costs, average fuel consumption by one or more vehicles.
- The information required to create long-term and short-term work plans in this business segment,
- More efficient business management system, analyzing and processing reports,
- No data redundancy,
- Eliminate unclear, incomplete, undefined requirements and overcome the problem of technological backwardness at work,
- The quality of operations is better as well as the mutual coordination of all users of company vehicles.
- Implemented reports in the IS should provide relevant information on the state of the observed business system, and will be the basis for faster management and a more efficient decision-making and management system.

The implementation process, its execution and automation

Defining the shape and appearance was realized in Access, while the external data sources were stored in the SQL server database.

The on-screen forms that represent the results of modeling business processes are shown further on.

After a successful login to the app, the home screen shows all the programmed functions. The content is visible: the system (part of the entire management information system), administration (management of all application objects), business partners (recorded by all business partners and persons in the application), lists of values (here is the skeleton system updated), registration of vehicles (entry on organization vehicles), the use of vehicles (recorded use of the vehicle), vehicle maintenance (these entries show routine servicing and repair), reports (starting programmed reports for work analysis), Description (part of the application), search (fast access to different information in this system).

Figure 8 – Home screen applications
Рис. 8 – Главный экран приложения
Slika 8 – Početni ekran aplikacije

Form programmed to be displayed on the screen: Record of the vehicle technical data

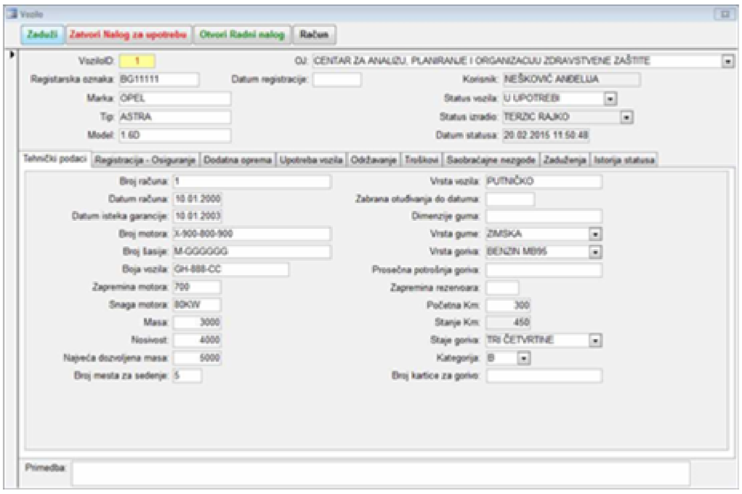


Figure 9 – Entering the technical data of the vehicle
Рис. 9 – Учет технических данных транспортного средства
Slika 9 – Unos tehničkih podataka o vozilu

The most important technical data for each company vehicle used in the organization is entered into this programmed form.

Form programmed to be displayed on the screen: Vehicle registration

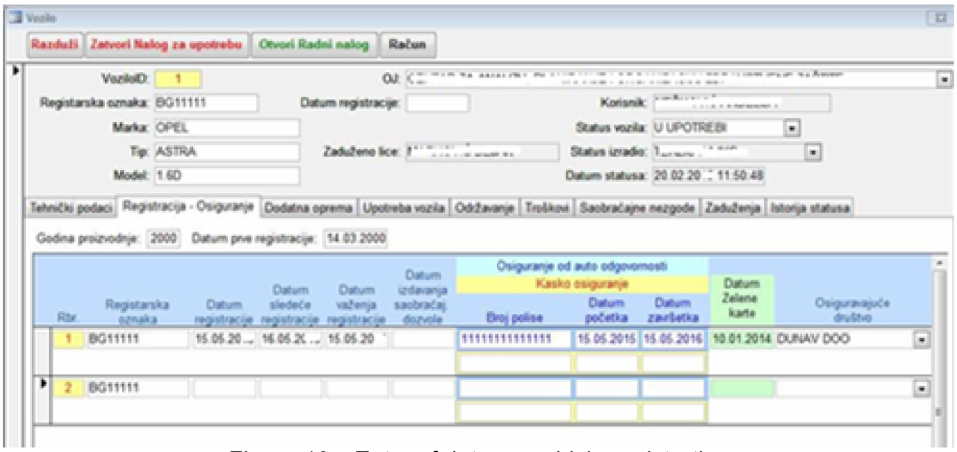


Figure 10 – Entry of data on vehicle registration
Рис. 10 – Учет данных о регистрации транспортного средства
Slika 10 – Unos podataka o registraciji vozila

Data relevant to the process of renewing the registration of vehicles is entered into this form.

Form programmed to be displayed on the screen: Entry of accessories

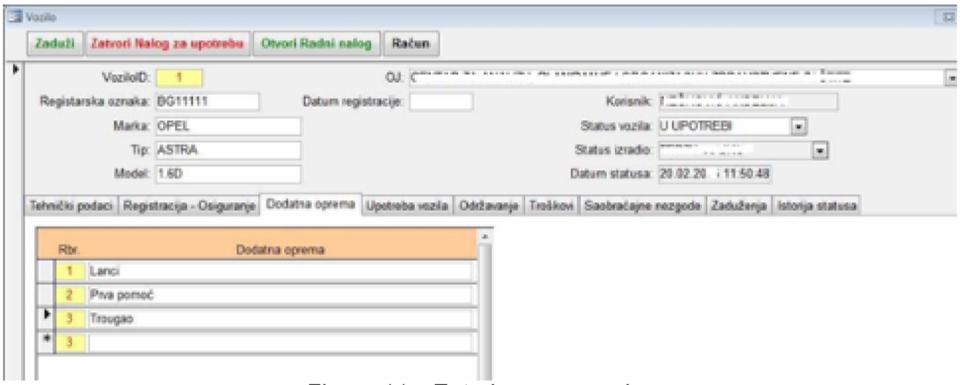


Figure 11 – Entering accessories
Рис. 11 – Ввод аксессуары
Slika 11 – Unos dodatne opreme

Data on accessories which go along with the borrowed vehicle is entered into this programmed form.

Form programmed to be displayed on the screen:
Use of the vehicle

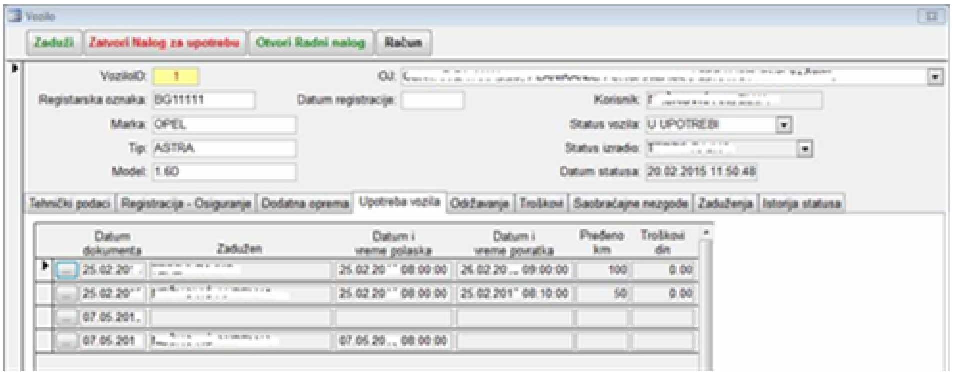


Figure 12 – Overview of the vehicle use
Рис. 12 – Сводный отчет по транспорту
Slika 12 – Pregled upotrebe vozila

This display form can quickly show the data on the use of vehicles, the mileage and expenses incurred during the use of vehicles.

Form programmed to be displayed on the screen:
Costs during the use of the vehicle

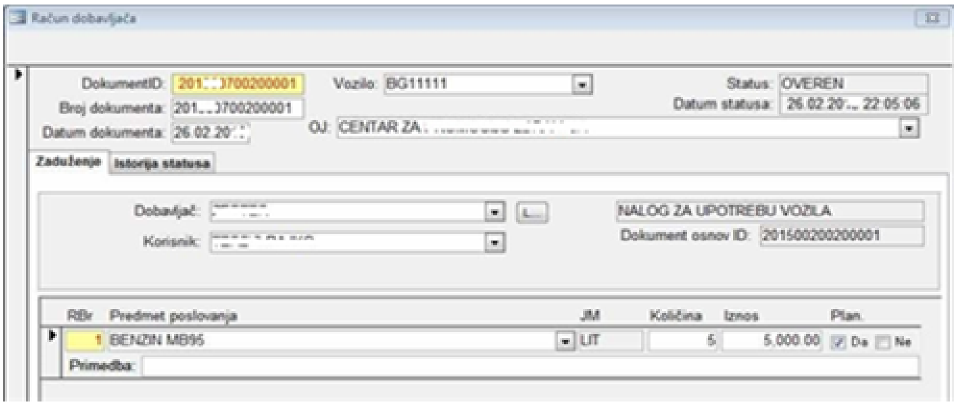


Figure 13 – Input of costs during the vehicle use
Рис. 13 – Накладные расходы во время использования транспортного средства
Slika 13 – Unos troškova tokom upotrebe vozila

Costs for each vehicle in the fleet are entered into this form.

Form programmed to be displayed on the screen: Costs

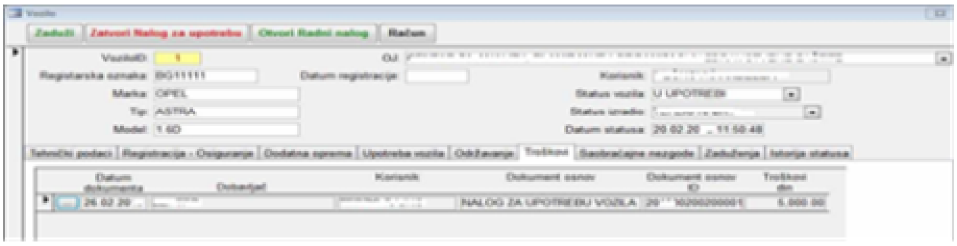


Figure 14 – Overview of costs for a selected vehicle
Рис. 14 – Обзор расходов по выбранному транспортному средству
Slika 14 – Pregled troškova za izabrano vozilo

This form shows a summary for each document created during the vehicle usage. There are dates and suppliers for each document as well as a total amount of costs.

Form programmed to be displayed on the screen: Allocating vehicles

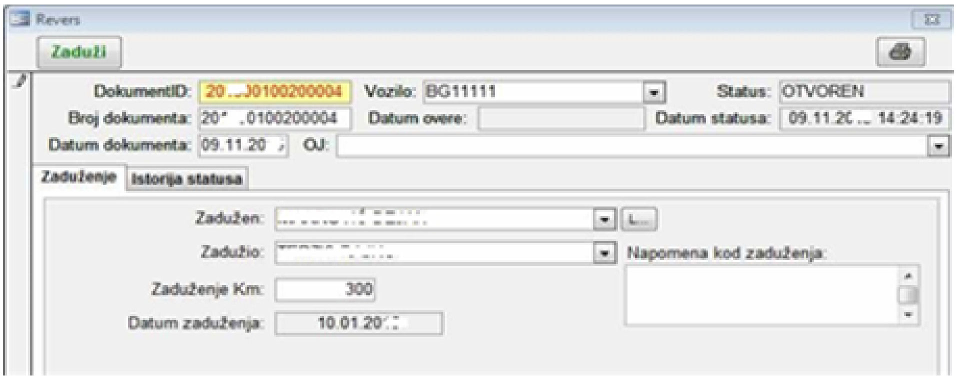


Figure 15 – Procedure of allocating vehicles
Рис. 15 – Процедура оформления транспортного средства
Slika 15 – Procedura zaduženja vozila

Vehicle allocation data is shown in this form: the name of the person the vehicle is allocated to, how many kilometers the vehicle has ordered in time duties, the time and any notes on the condition of the vehicle at the time of borrowing.

Form programmed to be displayed on the screen: Overview of the liabilities for vehicles

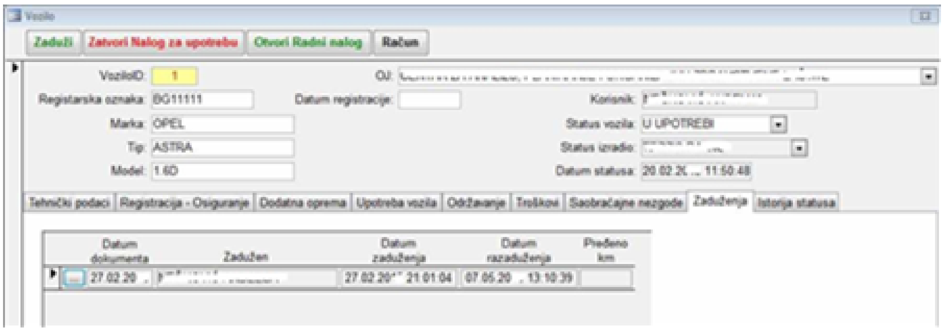


Figure 16 – Procedure of allocating vehicles
Рис. 16 – Процедура оформления транспортного средства
Slika 16 – Procedura zaduženja vozila

This form shows the listing tasks and the use of each vehicle.

Each vehicle in the organizationis allocated with a receipt and the liability for each vehicle is determined. This screen contains the history of the vehicle usage.

Form programmed to be displayed on the screen: Return of the vehicle

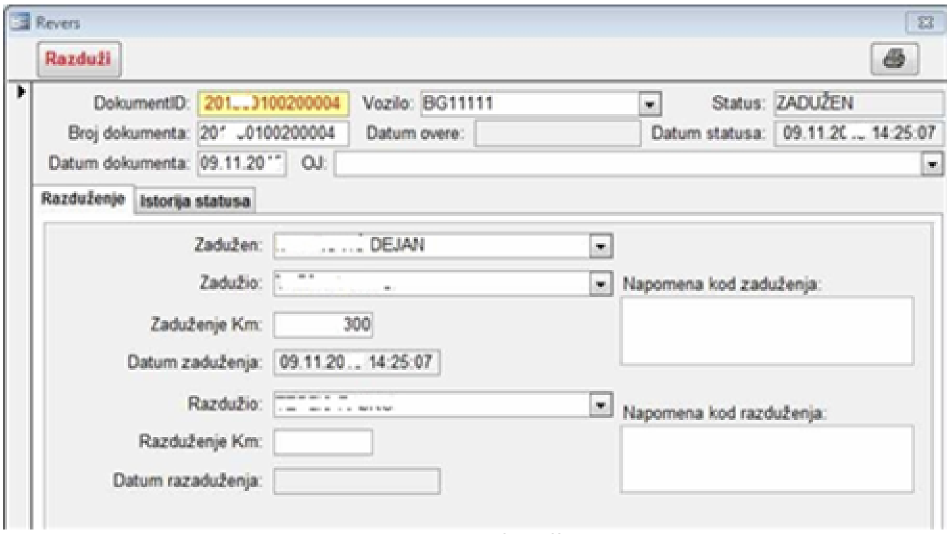


Figure 17 – Paperwork procedure for officially returning vehicles
Рис. 17 – Процедура закрытия путевых листов
Slika 17 – Postupak razduženja vozila

After a period of vehicle use, a person liable for the vehicle is to return it. At that point, the following data is entered: date of the official return of the vehicle, the person who returned the vehicle, the mileage on the date of return, as well as the description of the condition of the vehicle at the time of return.

Form programmed to be displayed on the screen: Vehicle ride order

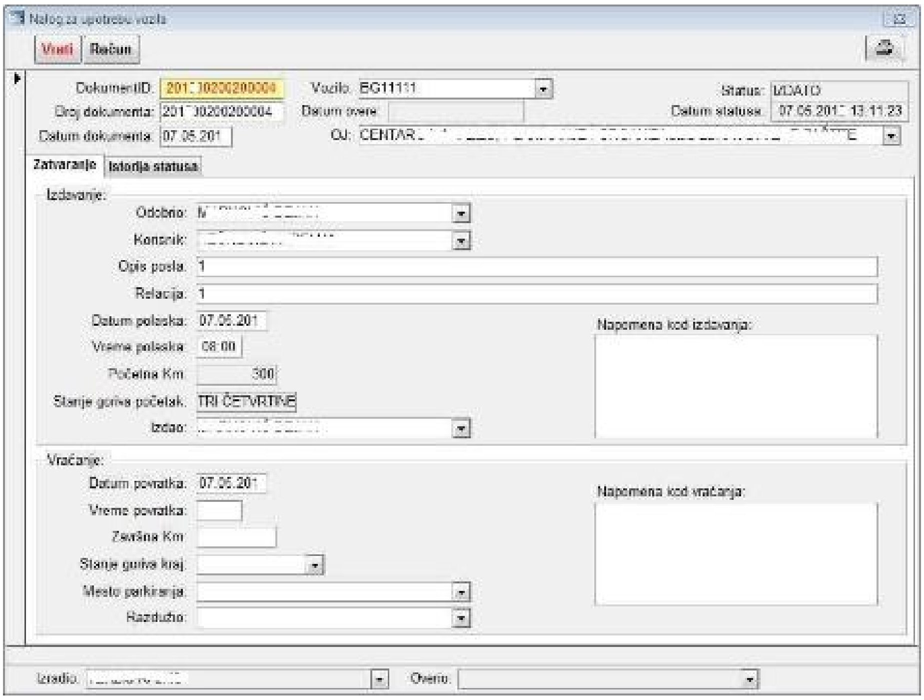
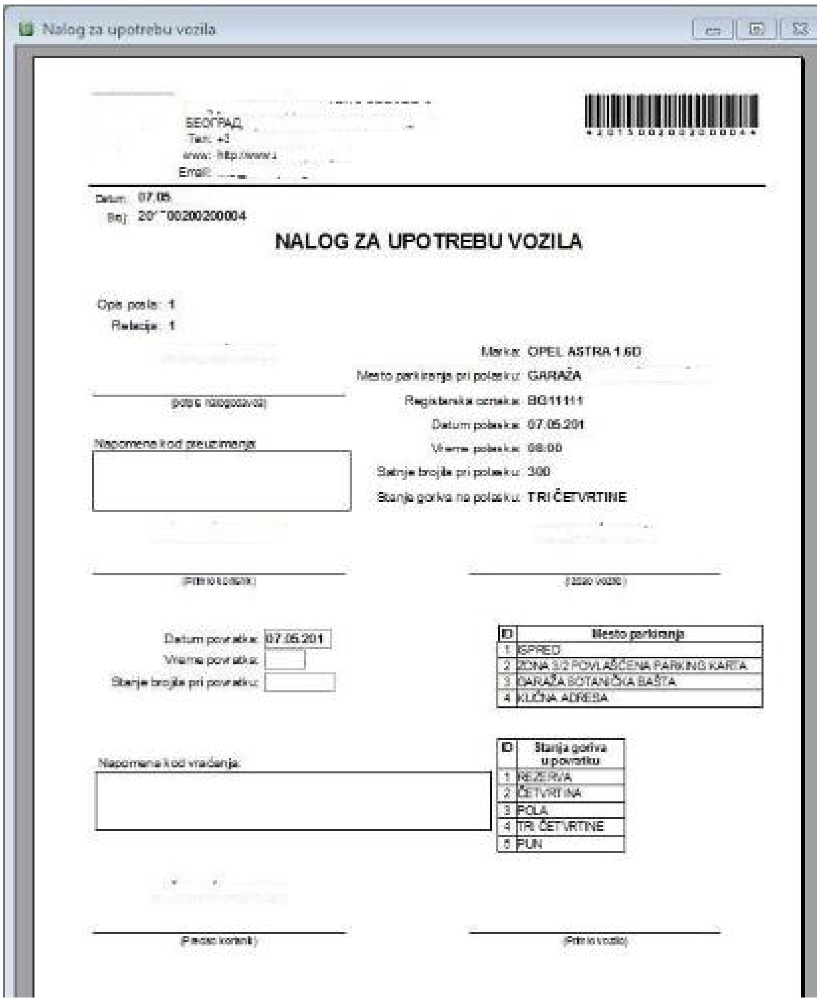


Figure 18 – Procedure of opening a vehicle ride order
Рис. 18 – Порядок выписки путевого листана транспортное средство
Slika 18 – Procedura otvaranja naloga za upotrebu vozila

When the use of a company vehicle has been approved, a ride order for a passenger vehicle is opened. The entries are: ground vehicle use – the purpose for using the vehicle and the distance, the date and the time of taking over the vehicle, the initial state of the odometer, fuel level in the tank and the person who approved the use of the vehicle.

Upon completion of the vehicle usage, the date and the time of return of the vehicle are recorded. In addition, the final entries are the mileage, fuel level upon return, a place to park and the person who took the car keys.

Output document:
Printed ride orders for passenger vehicles


Nalog za upotrebu vozila

БЕОГРАД,
Тел: +3
www: http://www.
Email:

Datum: 07.05.
Broj: 20''00200200004

NALOG ZA UPOTREBU VOZILA

Opis posla: 1
Relacija: 1

Marka: OPEL ASTRA 1.6D
Mesto parkiranja pri polasku: GARAŽA
Registarska oznaka: BG11111
Datum polaska: 07.05.201
Vreme polaska: 08:00
Stanje brojila pri polasku: 300
Stanje goriva na polasku: TRI ČETVRTINE

(potpis nalogodavca)

Napomena kod preuzimanja:

(Primio korisnik) (Izdao vozilo)

Datum povratka: 07.05.201
Vreme povratka:
Stanje brojila pri povratku:

ID	Mesto parkiranja
1	SPREO
2	ZONA 3/2 POVLAŠĆENA PARKING KARTA
3	GARAŽA BOTANIČKA BAŠTA
4	KUĆNA ADRESA

Napomena kod vraćanja:

ID	Stanja goriva u povratku
1	REZERVA
2	ČETVRTINA
3	POLA
4	TRI ČETVRTINE
5	PUN

(Predao korisnik) (Primio vozilo)

Figure 19 – Procedure of handing in a vehicle ride order
Рис. 19 – Порядок оформления заявки на использование транспортного средства
Slika 19 – Procedura predaje naloga za upotrebu vozila

At the beginning of the process, the employee receives initially filled ride order. Upon completion of the use of the vehicle, the employee returns the completed ride order for passenger vehicles with the data on kilometers ordered, a place to park the vehicle and the date and the time of the vehicle delivery.

Conclusion

Completely new directions in the organization of business processes are being created and of particular importance is the development of a system for managing business processes, based on explicitly designed processes and providing support in the execution and management of operational business processes.

An important requirement is knowledge of business processes. The main contribution of this paper is defining the approach for modeling and implementing business processes through a selection of tried and tested methods and models for dealing with the complexities of system selection and implementation of executive decisions.

This paper presents an approach for modeling business processes through a choice of methods and models for coping with the complexity of the system (Mayer, et al., 1995). The application of the proposed methods and models is illustrated through the decomposition of business processes and a detailed specification of the business process in creating ride orders for passenger vehicles.

The presented example of defining the process model of a ride order for passenger vehicles is a way to simultaneously describe the dynamics of information for the IS development. Using contemporary design and the use of CASE tools can be extended and modified, because all changes are easily installed. The presented methodology for the design of information systems and CASE tools can be used for any system or phenomenon studied and implemented on a computer (Lazarevic et al., 2006).

Precisely and formally defined business process models were the basis for configuring the IS, but will be used for the analysis, understanding and continuous improvement of the process they describe. It is important to identify and describe all the processes; otherwise, the system will be incomplete. Being living organisms, business processes are not standardized, but they can be optimized.

Establishing business process management is not only an aspect of understanding the flow of operations and other elements of organizational design. Other dimensions of establishing business processes are accurate implementation of functionality to the design of business processes, business process improvement and alignment with the solution of this improvement, management of changes in the design process that arise during the implementation of solutions, the introduction of end-users to work and training about specific functionalities related to administration for a process in which they are protagonists.

This paper presents a combination of theory and practice as theoretical aspects are exposed to real results. The paper shows the implementation processes, their implementation and their automation.

The executive specification of the program is realized on the Access / SQL Server platform.

The appearance of screen forms was implemented on the MS Access platform, while the external data sources were stored in the SQL server database.

The automated solution increases the quality of operations and coordinates all the participants in this business system.

The ultimate goal is the development of an IS which will be based on business processes, i.e.in which business processes will be first-order entities. Precisely and formally defined business process models will be the basis for configuring the IS, but will also be used for the analysis, understanding and continuous improvement of the process they describe (Terzić, et al., 2014). This IS concept will be able to continuously offer an adequate support to business systems and it will enable successful achievement of business objectives of organizations.

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АВТОМАТИЗАЦИЯ ВЫПИСКИ ПУТЕВЫХ ЛИСТОВ НА ЛЕГКОВЫХ АВТОМОБИЛЕЙ

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ОБЛАСТЬ: компьютерные науки, информационные технологии, промышленное программное обеспечение
ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

Эффективная деятельность организации зависит от качества управления взаимосвязанными и бизнес-процессами. Информационная система VozIS разработана с целью обеспечения ввода данных, в тех областях, где это необходимо.

Благодаря автоматизированному учету данных о служебных автомобилях их использовании и сервисе (в т.ч. о регистрации, страховании, ремонте, путевых листах, накладных расходах и пр.) созданы реальные условия для эффективного управления деловой системы, контроля финансовых средств, долгосрочного и краткосрочного планирования деятельности, а также для оформления отчетов.

Система VozIS исключает все нечеткости, неполные заявки и ускоряет технологический процесс работы. Автоматизация повышает качество делопроизводства, координируя всеми участниками деловой системы. В статье ставится акцент на применяемые методы бизнес-анализа и приведены результаты проектирования в области разнарядки путевых листов легковых автомобилей и деловых процессов, связанных с данной областью.

Ключевые слова: *служебный автомобиль, путевой лист, транспортное средство, BPMN, UML, BPM, системы управления бизнес-процессами, бизнес-процесс.*

AUTOMATIZACIJA PUTNOG NALOGA ZA PUTNIČKA VOZILA

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OBLAST: računarske nauke, informatika, industrijski softver
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Sažetak:

Efikasnost funkcionisanja organizacije zavisi od kvaliteta upravljanja međusobno povezanih i međusobno zavisnih poslovnih procesa. Informacioni sistem VozIS projektovan je tako da obezbedi unos podataka tamo gde oni i nastaju. Evidencijom podataka o službenim vozilima, njihovoj upotrebi i održavanju (poslovnim procesima registracije, osiguranja, servisiranja, putnim nalozima, troškovima vezanim za potrošnju goriva) stvaraju se realni uslovi za efikasno upravljanje poslovnim sistemom, kontrolu finansijskih troškova, za izradu dugoročnih i kratkoročnih planova rada i različitih izveštaja. VozIS eliminiše nejasne, nekompletne zahteve i premošćava trenutnu tehnološku zaostalost u radu. Automatizovano rešenje podiže kvalitet poslovanja i koordinira sve aktere u ovom poslovnom sistemu. Težište ovog rada predstavlja prikaz metoda poslovne analize. Navedeni su i rezultati projektovanja na segmentu putni nalog za putnička vozila i poslovnim procesima koji su tesno povezani sa njim.

Ključne reči: *službeno vozilo, putni nalog, vozilo, BPMN, UMM, BPM, sistemi upravljanja poslovnim procesima, poslovni proces.*

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EVACUATION FROM TUNNELS - AN EXAMPLE OF THE STRAŽEVICA TUNNEL

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Abstract:

Tunnels are passageways built for different purposes: road tunnels, railway tunnels, subway tunnels or similar. Their dimensions are becoming more and more considerable, depending on technology improvement. According to the fact that many people and vehicles pass continually through these structures, there was a logical question about a possible evacuation in case of disasters such as fire, explosion or similar. This is a constantly open and actual problem, confirmed by many people who perished in disasters because they could not be evacuated or because an evacuation was delayed for some reasons. This paper has been written to show a possible evacuation situation and to calculate the minimum time for the evacuation in the case of 772 m long Straževica tunnel.

Key words: *evacuation, simulation, tunnels.*

Introduction

Tunnels, generally, present underground objects, with both ends opened, positioned horizontally or with a slight gradient, which serve for railway, road, water ways, or similar, and connect two parts of the road separated by an obstacle that could not be overcome in some other way. The biggest number of tunnels, often the longest of tunnels, was built for railway transport and transport by water, while a smaller part was built on roads and pedestrian crossings. Tunnels, as well as bridges, present the most complicated architectural structures. Their construction demands great knowledge, detailed planning, many different measurements and huge material expenses. Some examples of tunnels are presented in Figure 1.

Figure 1 – Tunnels for traffic in Baltimore (left) and Switzerland (right), figure sources: https://en.m.wikipedia.org/wiki/Cut_and_cover#Cut-and-cover (left), https://www.ethz.ch/en/news-and-events/eth-news/news/2013/11/a-land-of-tunnels.html (right)
Рис. 1 – Автодорожные тоннели в Балтиморе (слева) и Швейцарии (справа), источник фото: https://en.m.wikipedia.org/wiki/Cut_and_cover#Cut-and-cover (слева), https://www.ethz.ch/en/news-and-events/eth-news/news/2013/11/a-land-of-tunnels.html (справа)
Slika 1 – Tuneli za saobraćaj u Baltimoru (levo) i Švajcarskoj (desno), izvor slike: https://en.m.wikipedia.org/wiki/Cut_and_cover#Cut-and-cover (levo), https://www.ethz.ch/en/news-and-events/eth-news/news/2013/11/a-land-of-tunnels.html (desno)

Tunnels can be divided in several ways, depending on different factors. Depending on their position in respect to the ground, tunnels are divided to hill tunnels, underwater tunnels and city tunnels. Depending on their structure, tunnels can be divided to completely constructed tunnels, partly constructed tunnels and no constructed tunnels. As far as the applied construction method is concerned, there are Belgian, Austrian, English, German, Italian and other methods of tunnel construction. There are also many other different divisions of tunnels. From the historical aspect, it was known that tunnels were built in 2500 B.C. under the rivers Tigris and Euphrates. Today, there are many tunnels with different purposes all over the world. Some of the longest tunnels are presented in Table 1.

Table 1 – The longest tunnels in the world
Таблица 1 – Самые длинные тоннели в мире
Tabela 1 – Najduži tuneli na svetu

Name of the tunnel	Location of the tunnel	Length of the tunnel	Purpose	Year
Delaware Aqueduct	New York, USA	137 km	Water supply	1945
Päijänne Water Tunnel	Finland	120 km	Water supply	1982

Name of the tunnel	Location of the tunnel	Length of the tunnel	Purpose	Year
Dahuofang Water Tunnel	Liaoning Province, China	85.32 km	Water supply	2009
Orange–Fish River Tunnel	South Africa	82.8 km	Water supply	1972
Bolmen Water Tunnel	Kronoberg/Scania, Sweden	82 km	Water supply	1987
Tunnel Emisor Oriente	Mexico City, Mexico	62.5 km	Water waste	2012
Guangzhou Metro: Line 3	Guangzhou, China	60.4 km	Metro	2010
Beijing Subway: Line 10	Beijing, China	57.1 km	Metro	2012
Seikan Tunnel	Tsugaru Strait, Japan	53.8 km	Railway Single Tube	1988
Želivka Water Tunnel	Central Bohemian Region, Czech Republic	51.075 km	Water supply	1972

The Straževica tunnel presents a component of Belgrade's detour and it is the largest and the most modern tunnel in Serbia. It presents an integral part of the KORIDOR 10 highway. The tunnel was built in accordance with the latest world standards. The length of the tunnel is 772 m while the complete width is 13 m and the width of the roadway is 11.5 m. It is only the right tunnel tube. The left tunnel tube was realized for only 115 m. The both tunnel tubes should be connected with two pedestrian tunnels with a tunnel cross-section of 25 m^2, intended for evacuation in emergency cases. The tunnel is equipped with complete light and traffic signalization equipment. It also has a very modern system for fire detection, burglary detection, air control, audio and radio system, ventilation system and a system for traffic control. Six lighting systems accommodate the tunnel light to the day light and, in that way, stop the "blindness" of drivers. The complete quantity of dug earth was 70,000 m^3. In order to stop the ground moving, it was necessary to concrete a protective inclined plane of 120 m in length, with 147 tensioned anchors with a length of 9 m. The tunnel excavation was realized by a new Austrian tunnel method. Some of important data for the tunnel are presented in Table 2, while the tunnel is presented in Figure 2 (left and right) (http://www.energoprojekt-ng.rs), (http://www.novosti.rs/vesti/beograd.74.html:378392-Strazevica).

Table 2 – Major data for the Straževica tunnel
Таблица 2 – Главные параметры тоннеля Стражевица
Tabela 2 – Glavni podaci za tunel Straževica

tunnel length	745m +115m
tunnel cross-section	110 m2
tunnel excavation	843,377.00 m3
open-cut excavation	150,390.23 m3
earth fill	79,175.05 m3
gravel fill	80,128.86 m3
concrete lining	18,945.39 m3
concrete MB 30	2,547.61 m3
sprayed concrete MB 30	3,753.08 m

Figure 2 – The entrance at the Straževica tunnel (right) and its inside look (left) (Figure source): http://www.telegraf.rs/vesti/beograd/1083872-obustavljen-saobracaj-kod-tunela-strazevica (left), http://glassrbije.org/sr/ чланак/за-завршетак-тунела-стражевица-обезбеђено-450-милиона (right)
Рис. 2 – Вход в тоннель Стражевица (справа) внутренний вид (слева) (источник фото) http://www.telegraf.rs/vesti/beograd/1083872-obustavljen-saobracaj-kod-tunela-strazevica (слева), http://glassrbije.org/sr/ чланак/за-завршетак-тунела-стражевица-обезбеђено-450-милиона (справа))
Slika 2 – Ulaz u tunel Straževica (desno) i unutrašnji izgled (levo)(izvor slike): http://www.telegraf.rs/vesti/beograd/1083872-obustavljen-saobracaj-kod-tunela-strazevica (levo), http://glassrbije.org/sr/ чланак/за-завршетак-тунела-стражевица-обезбеђено-450-милиона (desno))

Pathfinder 2012 simulation software

Pathfinder presents an agent-based on egress and human movement simulator. There are several different versions of this program. Pathfinder provides a graphical user interface for a simulation design and execution as well as 2D and 3D visualization tools for a result analysis. The movement environment is a 3D triangulated mesh designed to match the real dimensions of a building model. This movement mesh can be entered manually or automatically based on imported data (e.g. FDS geometry). Walls and other impassable areas are represented as gaps in the navigation mesh. The construction of curved walls could be realized as a construction of several straight wall segments. These objects are not actually passed along to the simulator, but are represented implicitly because occupants cannot move in places where no navigation mesh has been created. Doors are represented as special navigation mesh edges. Every door has its own length. In all simulations, doors provide a mechanism for joining rooms and tracking the occupant flow. Depending on the specific selection of simulation options, doors may also be used to explicitly control the occupant flow. Stairways are also represented as special navigation mesh edges and triangles. Stairways can connect different floors and levels. The occupant movement speed is reduced to a factor of their level travel speed based on the incline of the stairway. The occupant speed could be defined for different evacuation scenarios. Each stairway implicitly defines two doors. These doors function just like any other door in the simulator but are controlled via the stairway editor in the user interface to ensure that no geometric errors result from a mismatch between stairways and the connecting doors.

Occupants are modeled as upright cylinders on the movement mesh and travel using an agent-based technique called inverse steering. Each occupant calculates movements independently and can be given a unique set of parameters (maximum speed, exit choice, 3D model, etc). Pathfinder supports two movement simulation modes. In "Steering" mode, doors do not act to limit the flow of occupants; instead, occupants use the steering system to maintain a reasonable separation distance. In the SFPE mode, occupants make no attempt to avoid one another and are allowed to interpenetrate, but doors impose a flow limit and velocity is controlled by density. Simulator users can freely switch between the two modes within the Pathfinder user interface and compare answers. The example of occupants' movement in a simulation model of the Straževica tunnel at 385 m from the tunnel exit/entrance is presented in Figure 3.

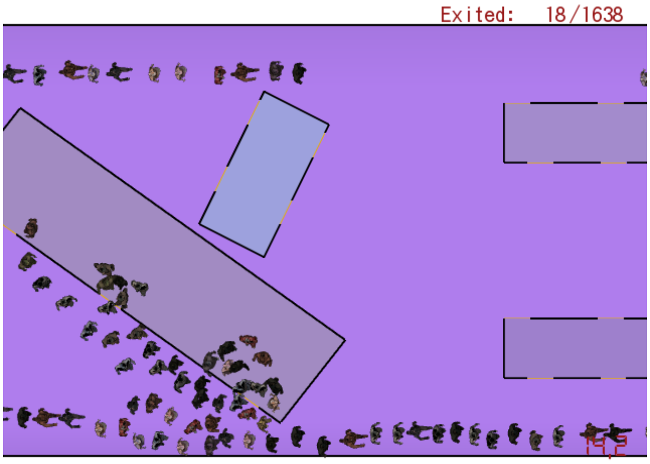

Figure 3 – Modeled occupants in the tunnel simulation model after 14.2 seconds from the start of the simulation
Рис. 3 – Смоделированные пассажиры в симуляционной модели тоннеля спустя 14,2 секунды от начала симуляции
Slika 3 – Modelovani ljudi u simulacionom modelu tunela posle 14,2 sekunde od početka simulacije

A very important software possibility is importing files created in 3D CAD, FDS and PyroSim. These files have their own geometry which can be used in Pathfinder and significantly save time needed to complete the whole evacuation and fire project. The imported geometry is sent as-is to 3D Results, resulting in a clean and fast graphical representation of the data. The used version of Pathfinder for paper results was 2012 version (Thunderhead, 2012, pp.1-4).

Simulation model

The simulation model was realized in Pathfinder 2012 in accordance with its real dimensions. Because of the program possibilities, the curves of the tunnels were not completely realized but that did not influence the simulation results. The similar approximations were used in some earlier published papers (Jevtić, Ničković, 2014, pp.RT6.6.,1-4), (Jevtić, 2014b, pp.537-541), (Jevtić, 2015, pp.545-550).

The simulation was realized for different occupants' speeds (1.25 m/s, 1.5 m/s, 1.75 m/s, 2m/s, 2.5 m/s, 3m/s, 3.5 m/s and 5 m/s) in the case of a collision. The occupants were positioned in their vehicles at the start of the simulation. According to the postulated scenario, the tunnel was full with different vehicles. There were 199 cars, 14 buses and 15 trucks.

Every car had 4 occupants inside, every bus had 58 occupants inside and every truck had 2 occupants inside. The complete number of occupants was 1,638. The dimensions (length, width, height) of every car were 4.2 m x 1.8 m x 1.6 m, the dimensions of every bus were 13 m x 2.65 m x 3.2 m and the dimensions of every truck were 18.75 m x 2.85 m x 3.2 m. Every vehicle had a determined number of doors- cars had 4 exit doors, busses had 3 exit doors and trucks had 2 doors. The distance between every two vehicles was 1m. The vehicles were positioned in two separate roadways. The collision between a bus and a car was in the middle of the tunnel, at 386 m after the entrance/exit of the tunnel. The vehicles in the middle of the tunnel and the collision situation are presented in Figure 4.

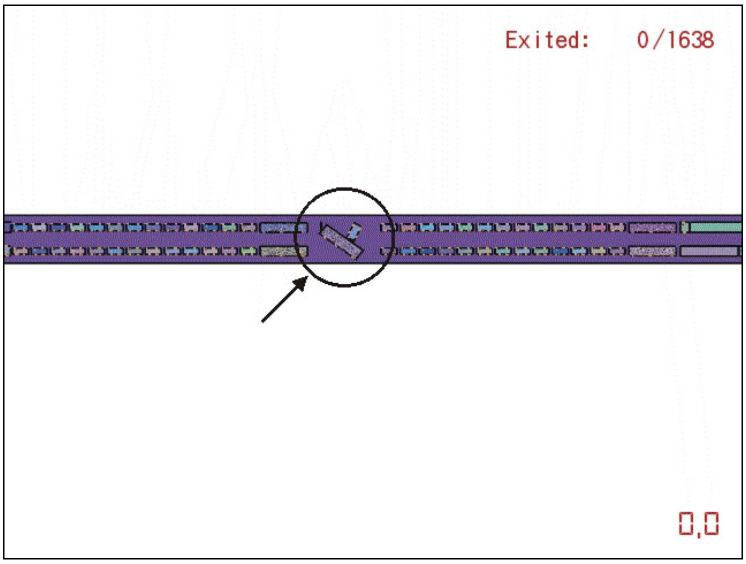

Figure 4 – The simulation example for the second scenario with the noted location of crash at the start of the simulation
Рис. 4 – Симуляционный пример по второму сценарию с обозначенным местоположением аварии в начале симуляции
Slika 4 – Simulacioni primer drugog scenarija sa obeleženom lokacijom sudara na početku simulacije

Simulation results

Some scenes from the case where the occupants' speed was 1.5 m/s are presented in Figures from 5 to 12, while the complete simulation results were presented in Figure 13.

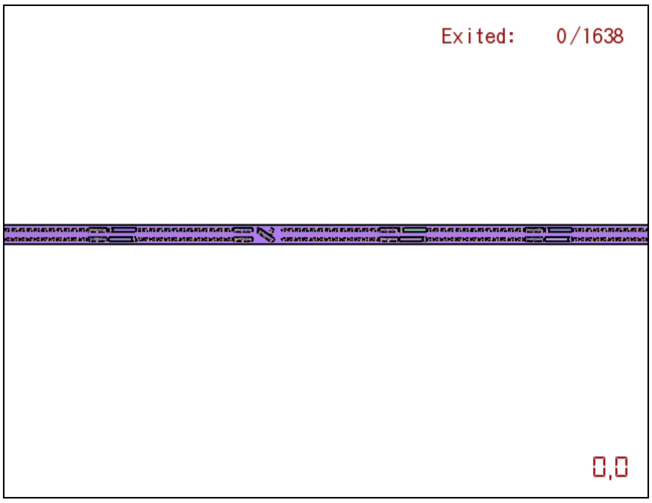

Figure 5 – The simulation example for the noted case with the noted location of crash at the start of the simulation
Рис. 5 – Симуляционный пример приведенного случая с обозначенным местоположением аварии в начале симуляции
Slika 5 – Simulacioni primer za pomenuti slučaj sa obeleženom lokacijom sudara na početku simulacije

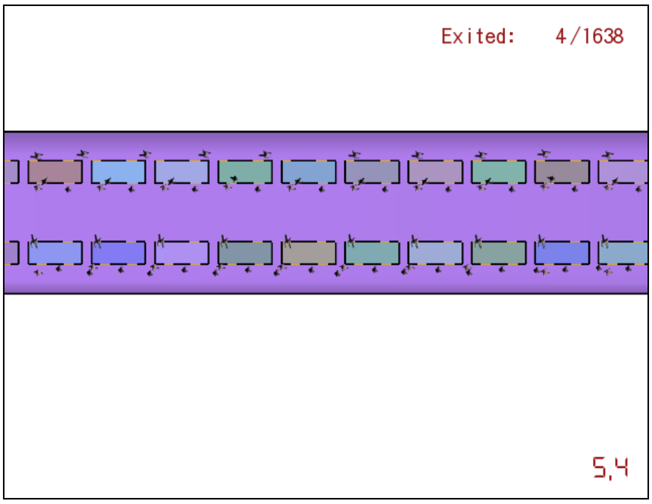

Figure 6 – The simulation example for the noted case after 5.4 seconds from the start of the simulation
Рис. 6 – Симуляционный пример приведенного случая спустя 5.4 секунды от начала симуляции
Slika 6 – Simulacioni primer za pomenuti slučaj posle 5,4 sekunde od početka simulacije

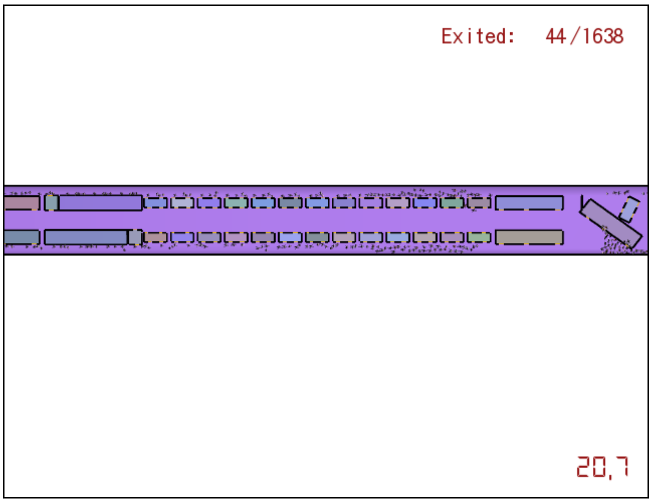

Figure 7 – The simulation example for the noted case after 20.7 seconds from the start of the simulation
Рис. 7 – Симуляционный пример приведенного случая спустя 20.7 секунд от начала симуляции
Slika 7 – Simulacioni primer za pomenuti slučaj posle 20,7 sekundi od početka simulacije

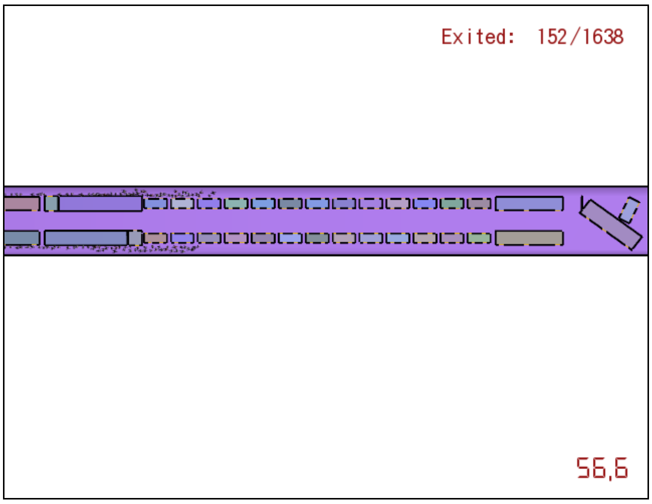

Figure 8 – The simulation example for the noted case after 56.6 seconds from the start of the simulation
Рис. 8 – Симуляционный пример приведенного случая спустя 56.6 секунд от начала симуляции
Slika 8 – Simulacioni primer za pomenuti slučaj posle 56,6 sekundi od početka simulacije

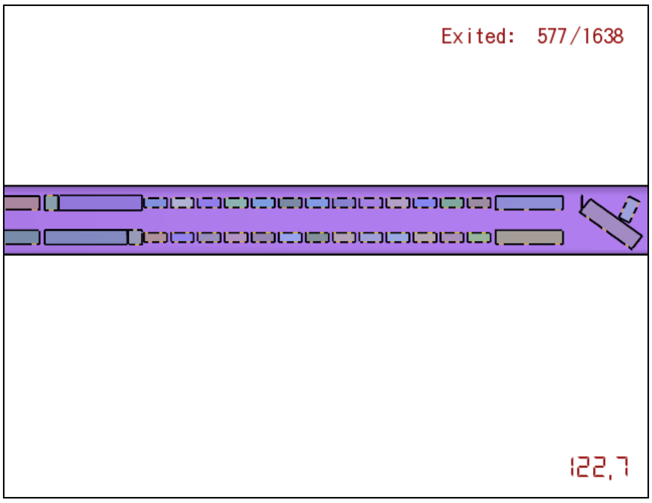

Figure 9 – The simulation example for the noted case after 122.7 seconds from the start of the simulation
Рис. 9 – Симуляционный пример приведенного случая спустя 122.7 секунд от начала симуляции
Slika 9 – Simulacioni primer za pomenuti slučaj posle 122,7 sekundi od početka simulacije

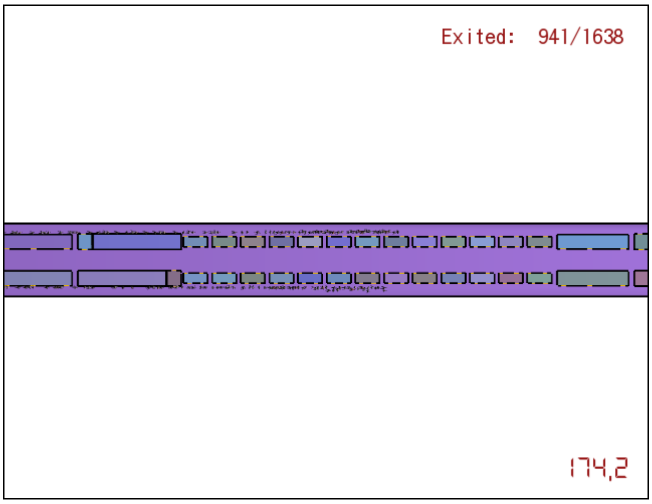

Figure 10 – The simulation example for the noted case after 174.2 seconds from the start of the simulation
Рис. 10 – Симуляционный пример приведенного случая спустя 174.2 секунды от начала симуляции
Slika 10 – Simulacioni primer za pomenuti slučaj posle 174,2 sekunde od početka simulacije

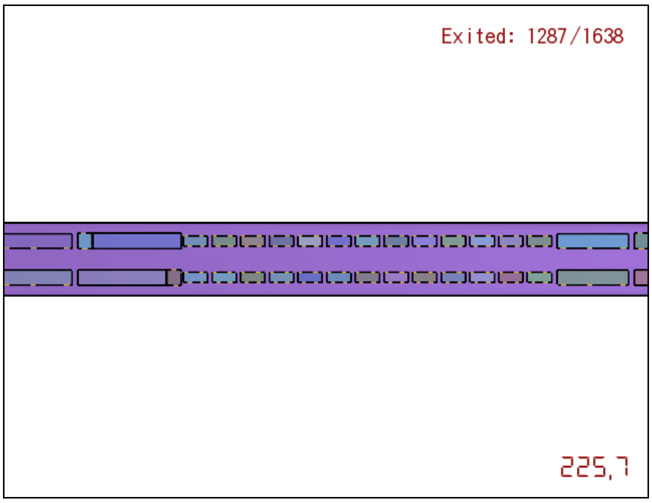

Figure 11 – The simulation example for the noted case after 225.7 seconds from the start of the simulation
Рис. 11 – Симуляционный пример приведенного случая спустя 225.7 секунд от начала симуляции
Slika 11 – Simulacioni primer za pomenuti slučaj posle 225,7 sekundi od početka simulacije

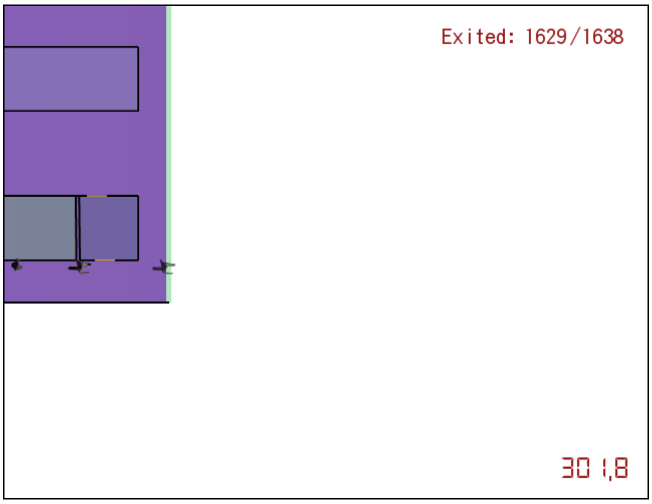

Figure 12 – The simulation example for the noted case at the exit/entrance of the tunnel after 301.8 seconds from the start of the simulation
Рис. 12 – Симуляционный пример приведенного случая спустя 301.8 секунд от начала симуляции
Slika 12 – Simulacioni primer za pomenuti slučaj posle 301,8 sekundi od početka simulacije

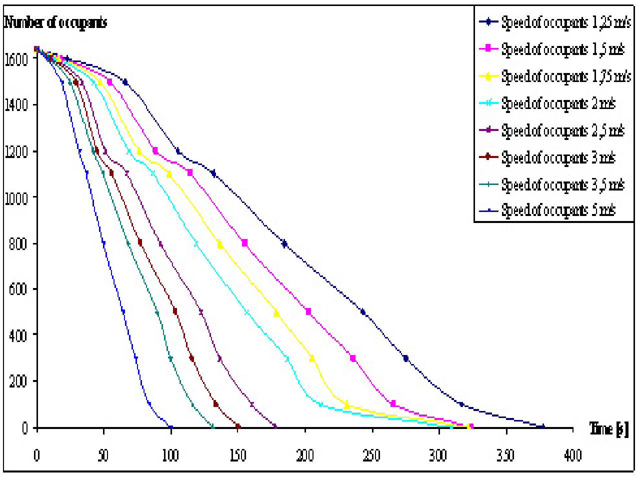

Figure 13 – Simulation results for realized cases
Рис. 13 – Результаты моделерования симуляционных событий
Slika 13 – Rezultati sumulacije za realizovane slučajeve

Analysis of the results

The simulations were realized on a laptop Lenovo IdeaPad G50-80 80E502F3YA, with the Intel Core i5-5200U processor (2 cores, 2.20GHz, 3MB cache), DDR3L memory controller (up to 1600MHz), Intel Turbo Boost 2.0 (2.70GHz) and 8GB of DDR3 RAM. The realized simulations for the presumed cases showed mostly expected results. The simulations presumed a collision in the tunnel that barricaded the tunnel, without human victims. Lower occupants' speeds (1.25 m/s and 1.5 m/s) implied calm occupants, while higher occupants' speeds could imply occupants in panic (3.5 m/s, 5 m/s). The realized results showed that, for the chosen occupants' speeds, the evacuation time would be shorter for higher occupants' speeds; however, it does not mean that a very high occupant speed would imply very short evacuation time; on the contrary, in that case, the possibilities for unpredicted situations rapidly increase and evacuation time rapidly increases (Helbing, et al, 2000, pp.487-490).

Also, in the case of some collision with victims or some other consequences, such as fire, explosion, gas leakage or similar, speeds of occupants would be much different and their behavior would be chaotic and pretty unpredictable. That would imply different situations, such as panic, jams, injuries and similar. For example, it is very hard to leave a bus with jammed doors, since it is necessary to break the glass on the windows to leave the bus. Also, it is very hard to leave the tunnel with injured occupants that often have to be carried, which implies higher possibilities for jams and slower evacuation.

Conclusion

An analysis of evacuation times and evacuation routes using proper software presents a very helpful tool in evacuation realization because it gives a good presentation how the available evacuation routes could be used for different accidents (fire, earthquake, etc)(Jevtić, 2014a, pp.153-158). It is also possible to locate new evacuation routes that could be used in accidents (pedestrian tunnels) for successful evacuation. Testing these factors for different occupants' speeds and behaviors gives a good real presentation of a potential evacuation scenario inside the object and it offers great advantages in projecting and installing complete protection systems, such as fire protection systems, smoke protection systems, and similar (Netcu, et al, 2011, p.277). The application of this program for different objects puts it in the line with necessary engineer's tools for calculating and projecting safety evacuation systems for any type of evacuation causes (Serban, et al, 2014, pp.48-52).

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ЭВАКУАЦИЯ ИЗ ТОННЕЛЯ – НА ПРИМЕРЕ ТОННЕЛЯ СТРАЖЕВИЦА

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Резюме:

Тоннели представляют собой подземные сооружения различных типов назначения: железнодорожные, автодорожные, тоннели для метрополитенов и др. Благодаря технологическому развитию размеры тоннелей с каждым днем увеличиваются. Учитывая тот факт, что большой поток пассажиров и транспортных средств непрерывно проезжает через данные объекты, возникает естественный вопрос об их эвакуации в случае чрезвычайных ситуаций, таких как: пожар, взрыв и пр. Вопрос об эвакуации более чем актуален, так как подобные риски несут за собой большое количество человеческих жертв, если своевременно не предпринять меры по эвакуации.

В работе представлены возможные эвакуационные ситуации и минимальный расчет времени для эвакуационных мероприятий на примере тоннеля Стражевица 772 м.

Ключевые слова: *эвакуация, моделирование, тоннели.*

EVAKUACIJA IZ TUNELA – PRIMER TUNELA STRAŽEVICA

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OBLAST: saobraćaj
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Sažetak:

Tuneli su objekti sagrađeni za različite svrhe. Mogu biti putnički, železnički, tuneli za podzemne železnice i služiti za slične namene. Njihove dimenzije postaju sve veće zahvaljujući tehnološkim poboljšanjima. Uzimajući u obzir činjenicu da mnogo ljudi i vozila kontinualno prolazi kroz ove objekte, postavilo se pitanje o mogućoj *evakuaciji u slučaju katastrofa, kao što su požar ili eksplozija. Iskustva govore da je mnogo ljudi izgubilo život jer nisu mogli biti evakuisani ili je evakuacija zbog nekog razloga kasnila. U ovom radu opisuje se moguća evakuaciona situacija i izračunava minimalno vreme potrebno za evakuaciju u tunelu Straževica koji je dugačak 772 m.*

Ključne reči: *evakuacija, simulacija, tuneli.*

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LANDFILL SITE SELECTION USING GIS TECHNOLOGY AND THE ANALYTIC HIERARCHY PROCESS

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Abstract:

Landfills are one of the most common ways of waste disposal. Selecting a landfill site is a complicated and long process that involves a legal framework as well as environmental, economic and social parameters aimed at reducing a negative environmental impact. The landfill site selection in the municipality of Nevesinje (Republic of Srpska), dealt with in this paper, was performed using the analytic hierarchy process (AHP) and GIS technology. Eight criteria were analyzed: geology, distance from settlements, distance from road networks, distance from water bodies, vegetation, slope, elevation and aspect. Relative weighting factors for each criterion were defined by applying the AHP and their linear combinations, with the range of each cell determined by the suitability index. The suitability index has been reclassified in five classes where 67% of the territory belongs to the restricted area, 11% of the territory has low suitability, 6.1% has moderate suitability, 5.9% high suitability, and 10% very high suitability. Two potential landfill sites are proposed, but before a final decision is made, it is necessary to analyze additional parameters.

Key words: *landfill, site selection, AHP, GIS.*

Introduction

A lack of land for waste disposal, inadequate landfill sites and rapid population growth are some of the biggest problems of urban areas in the world. Landfills are an important element in the waste disposal management system. According to the Law on Waste Management of the Republic of Srpska (RS), a landfill is a site for waste disposal on the surface or below the surface where waste is disposed of, and that includes: internal storage areas, and a permanent site (over a year) which is used for temporary storage of waste (Official Gazette of the Republic of Srpska, 28/1994). The landfill site selection includes social and economic parameters, environment and legislation (Zamorano, et al, 2008, pp.473-481). An inadequate site selection causes: transfer of disease, pollution of water, soil and atmosphere, disruption of landscape value, unpleasant smell and economic losses. A site selection is a multi-criterion process which considers different criteria for the selection of suitable areas between different alternatives (Melo, et al, 2006, pp.83-92), (Nazari, et al, 2012, pp.1631-1642). The integration of GIS technology and the multi-criteria analysis is a powerful tool for the selection of a landfill site, because GIS enables an efficient manipulation and presentation of spatial data and the MCDA (multi-criteria decision analysis) consistently ranks potential sites based on different criteria (Kontos, et al, 2005, pp.818-832) and (Sener, et al, 2006, pp.376-388). Researchers use different MCDA methods for a landfill site selection. Siddiqui, et. al. (1996, pp.515-523) applied the combination of GIS and the Analytic Hierarchy Process (AHP). In (Chang, et al, 2008, pp.139-153) GIS and the fuzzy MCDA are integrated for a choice of locations in suburban areas, Tayyeb, et.al. (2010, pp.1073-1078) uses the MCDA and the analytic network process (ANP). Sener, et. al. (2006, pp.376-388) uses a combination of the AHP and linear combinations of weight, whereas (Akbari, 2008, pp.39-47) applied a combination of GIS, the Fuzzy multi-criteria analysis and the System Supporting Spatial Decision-making (SDSS). Mahini and Gholamalifard (2006, pp.435-445) described the multi-criteria analysis, called a linear combination of weight in the GIS environment.

In the site selection, it is very important to consider natural, social, political, economic and technical factors; therefore, a choice must be made by a multidisciplinary team of experts.

Methodology

Study area

Nevesinje is located in the southeastern part of the Republic of Serbian (BiH), east of Mostar and south of Sarajevo. It is located between latitude 43º04'- 43º29' N and longitude 17º58'- 18º25' E (Figure 1).

The Mulicipality is a mountainous region of High-Herzegovina with an average altitude of 860 m, and is characterized by a large karst field of 17,000 ha. The area of the Municipality of Nevesinje is 923.4 km^2. The Municipality Nevesinje has a population of 13,713 inhabitants (http://www.opstinanevesinje.rs.ba/,nd).

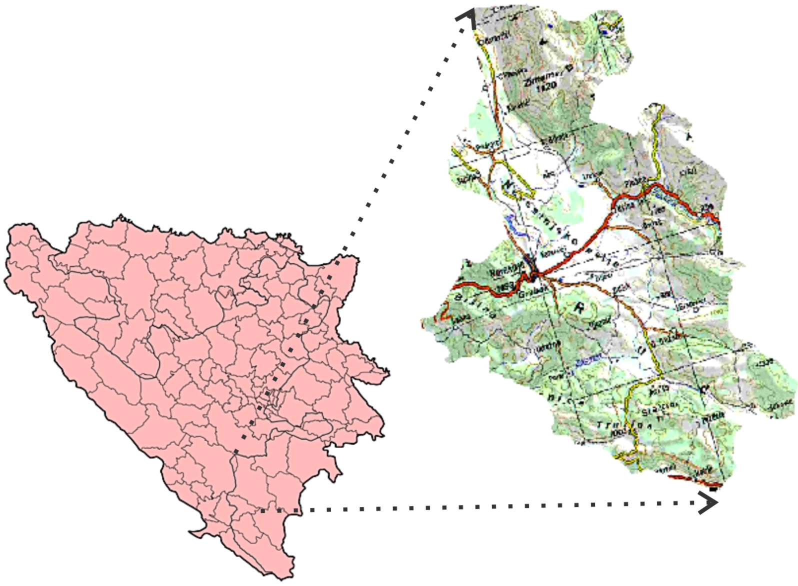

Figure 1 – Geographical location of the Municipality of Nevesinje in RS
Рис. 1 – Географическое положение Муниципалитета Невесинье, Республика Сербская
Slika 1 – Geografski položaj opštine Nevesinje, Republika Srpska

Method

A landfill site selection was carried out by a combination of GIS technology and the Analytic Hierarchy Process - AHP. GIS technology combines spatial data (maps, photogrammetric imagery, topography and satellite imagery) with quantitative, qualitative and descriptive databases and it supports a wide range of spatial analyses. In the decision making process, a large number of factors must be considered, and GIS is ideal for such studies because it allows easy manipulation of large amounts of spatial data from different sources. The AHP is a technique that, integrated into GIS, allows a consistent estimate, based on the factors that contribute to the analysis of problems. A schematic presentation is shown in Figure 2.

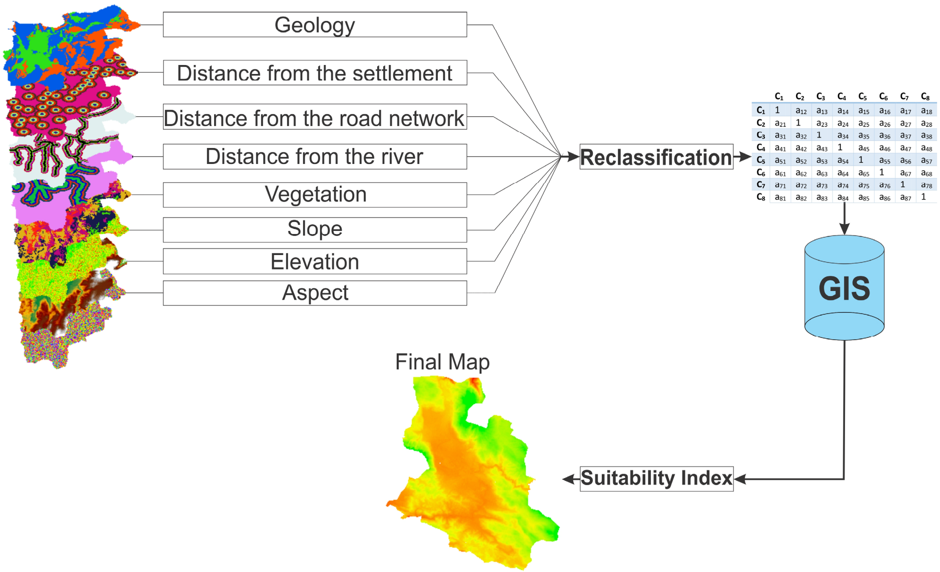

Figure 2 – Scheme of a landfill site selection using GIS and the AHP
Рис. 2 – Схема процесса выбора местности для обустройства свалки по ГИС технологии и методам AHP
Slika 2 – Šematski prikaz procesa izbora lokacije za deponiju primenom GIS tehnologije i AHP

The AHP is a powerful tool for consistent evaluation and entails four steps (Saaty, 2008, pp.83-98). The first step defines a problem. The second one is based on a representation of the problem in the hierarchical structure. The hierarchy structure consists of several levels: goal, criteria, sub-criteria and alternatives. The definition of the hierarchy structure for a landfill site selection includes environmental, economic and legal factors. In the third step, a matrix of comparison is generated as a result of a pairwise comparison of the elements of the hierarchy in the top-down sistem. The AHP provides a possibility to find relations between significant factors, establishes priorities with their relative importance in real conditions and determines the predominance of one factor. The goal is at the top of the hierarchy and it is not comparable. At the first level, n criteria were compared in pairs and with respect to a pattern element at a higher level. If an element A is n times preferred over B, then B is preferred 1/n over A. The comparison of two elements of the hierarchy, at the same level, is performed using Saaty's fundamental scale with 9 levels of relative importance - Table 1 (Saaty, 2008, pp.83-98).

Table 1 – Saaty's fundamental scale
Таблица 1 – Фундаментальная шкала Саати
Tabela 1 – Sartijeva fundamentalna skala

Importace	Definition
1	Equal importance
3	Weak dominance
5	Strong dominance
7	Demonstrated dominance
9	Absolut dominance
2,4,6,8	Intermediate values

The results of the comparisons of elements at a given level of the hierarchy are placed in the appropriate matrix A.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$$

The fourth step uses the comparison matrix to weigh priorities. In a completely consistent evaluation, the pairwise comparison matrix A, containing the comparison results, would be identical to the matrix X:

$$X = \begin{bmatrix} \frac{w_1}{w_1} & \cdots & \frac{w_1}{w_n} \\ \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \cdots & \frac{w_n}{w_n} \end{bmatrix}$$

where w_i denotes the relative weighted coefficient of the element *i.* The weight vector w_i can be calculated by solving the following system of homogenous linear equations: $A \cdot w = n \cdot w$ or $(A - n \cdot I) \cdot w = 0$
where n is the eigenvalue of the comparison matrix A.

The AHP allows the user to identify and analyze the consistency of decision-makers in the process of discernment and evaluation of the hierarchy elements. Also, it is possible to determine errors of judgment by calculating the consistency index (CI) for the comparison matrix, and then calculating the consistency ratio (CR).

$$CR = \frac{CI}{RI}$$

where *RI* is the random consistency index and it depends on the order of the matrix A.

$$CI = \frac{\lambda_{max} - n}{n-1}. \quad (1)$$

where λ_{max} is the largest eigenvalue of the comparison matrix. The closer the value of the computed *λmax* is to *n*, the more consistent the observed values are. If the consistency ratio is CR≤0.1, all results should be analyzed again (Inđić, et al, 2014, pp.23-41).

Finally, the sensitivity index is calculated using the linear combination of weight (WLC method), by multiplying the rank of each alternative with the weight factor:

$$S_i = \sum_{i=1}^{n} w_i \cdot r_j \quad (2)$$

Where S_i is the suitability index for a landfill site selection , w_i – the weight coefficient i, r_i – the rang j cells of the raster within the criteria i. Using equation (2) model expAhp 2.0. (http://www.arcgis.com/home/item.html?id=bb3521d...,nd) automatically calculates the sensitivity index S_i. A higher suitability index points to a higher possibility that a raster cell becomes a part of the landfill.

Criteria

After defining the goal, based on legislation and recommendations from literature, 5 limitations and 8 criteria (Table 3) were defined: geology, distance from settlements, distance from road networks, distance from surface streams, vegetation, slope, altitude and aspect (Zamorano, et al, 2008, pp.473-481), (Kontos, et al, 2005, pp.818-832), (Nazari, et al, 2012, pp.1631-1642), (Akbari, 2008, pp.39-47), (Gorsevski, et al, 2012, pp.287-296), (Zelenović, et al, 2011).

Geology

A landfill should be located in areas with a low risk of groundwater contamination. The contamination of groundwater primarily depends on the permeability and the depth of the strata beneath the landfill (Gorsevski, et al, 2012, pp.287-296). High permeability of the strata occurs in karst formations (such as limestone) and sandy soil, low permeability is characteristic for clayey soils, while the clay shales are impermeable (Kontos, et al, 2003, pp.267-277).

Distance from settlements

Landfills should not be built near urban or rural areas because of a negative impact on people's health, odor and noise. Studies have shown that with increasing the distance from inhabitated zones, the opposition of the population to landfill construction decreases (Akbari, 2008, pp.39-47). The EU Directive defines the minimum distance from residential areas which is 500 m (Official Journal of the European Union, Directive 2008/98 / EC).

Distance from road networks

An access to a landfill should be provided through alternative roads in all weather conditions (Sener, et al, 2010, pp.2037-46). On the other hand, landfills should be located near existing road networks because a construction of new roads leads to additional costs (Nas, et al, 2010, pp.491-500). Closer distances to the existing roads have higher weight.

Distance from water bodies

The Water Law of the Republic of Srpska prohibits the construction of landfills near water bodies (springs, rivers, lakes, wetlands) (Official Gazette of the Republic of Srpska, 50/2006 and 92/2009), (Nas, et al, 2010, pp.491-500). The EU Directive defines the minimum distance from permanent water streams and water sources, which is 500 meters (Official Journal of the European Union, Directive 2008/98/EC).

Vegetation

The Forests Law of the Republic of Srpska, prohibits waste disposal in forests and forest lands (Official Gazette of the Republic of Srpska, 66/2003, 75/2008 and 30/2010). Pastures, irrigated and non irrigated fertile areas are not suitable land for landfills.

Slope and elevation

Slope and elevation are the basic parameters for landfill construction (Kontos, et al, 2005, pp.818-832). Areas with high altitudes and slopes are not suitable for landfill sites. The best locations for landfills are areas of a medium altitude, surrounded by hills and with a slope less than 20% (Gorsevski, et al, 2012, pp.287-296). The slope affects the amount of water in the soil, the possibility of erosion rate, surface runoff and groundwater. The slope is crucial for the construction of landfill sites, because a higher slope causes higher costs of construction.

Aspect

The effect of wind must be taken into account because odors arising from landfills should not be felt in urban areas. Aspect oriented to the direction of prevailing winds is not suitable for a landfill site. By analyzing the strength and frequency of wind in the municipality of Nevesinje, it was found that the dominant direction of wind is north (N) and south (S), and the areas with this aspect have the lowest suitability.

Date collection and processing

After defining the goal, limitations and criteria, it is necessary to collect and enter data into GIS. In GIS, each of the limitations and criteria is presented in the form of a spatially defined vector or a raster map, the cells of which represent different alternatives. All GIS processes (digitalization, conversion, 3D analysis, etc.) during import and building of the spatial database, are accomplished using the tools of ArcGIS 10.2 software of the ESRI company (Nas, et al, 2010, pp.491-500). The sources and the process of generation of GIS data sets are given in Table 2.

Table 2 – Date sources
Таблица 2 – Источники данных
Tabela 2 – Izvori podataka

Criteria	Source
Geology	Basic geological map of 1: 100,000 (Released by the Military Geographical Institute, Belgrade)
Distance from settlements	Topographic map 1:50,000 (Military Geographical Institute, Belgrade)
Distance from road networks	
Distance from rivers	
Vegetation	Corina LandCover 2006 100 x 100 m (http://www.eea.europa.eu/, nd)
Slope	Digital terrain model [1] 20 x 20 m
Elevation	
Aspect	

Creating a distance from settlements, road networks and rivers was carried out using Multi Buffer tools. The slope and aspect have been created using the Slope and Aspect tool.

[1] Digital terrain model, resolution 20 m x 20 m, based on: ortho-photos (2011, 2013) and a digitized topographic map 1:50,000.

Criteria evaluation

After entering data into GIS, criteria were standardized and evaluated. In accordance with practice, experts experience and literature, the suitability of criteria, in this study, was determined using linear standardization in a score range from 1 to 5, where 5 is the highest and 1 is the lowest suitability (a cell) for a landfill site (Table 4). The reclassification (evaluation) of the criteria was carried out using the Reclass software package ArcGIS 10.2 tool (http://www.esri.com/software/arcgis/arcgis-for-desktop, nd).

Table 3 – Criteria and limitations
Таблица 3 – Критерии и удельные значения
Tabela 3 – Kriterijumi i ograničenja

Criteria	very low suitability	low suitability	moderate suitability	high suitability	very high suitability
C_1	al, K1,2,2JK	-	Pr+al, ßßab, ßß	-	2M1+2, 1M1+2, 2K2_2+3, J,K 3J,K
C_2	<500	500-1000	1000-1500	1500-2000	2000<
C_3	1000<	750-1000	500-750	250-500	250
C_4	<500	500-1000	1000-1500	1500-2000	2000<
C_5*	(311,312,313, 112,512,231)	(211,242,243)	(222,321, 324)	(333)	(332)
C_6	20<	-	10-20		0-10
C_7	1925<	1600-1925	1250-1600	900-1250	550-900
C_8	N	S	W,SW	NW	E,SE,NE,T

*CORINA 2006 legend

Determination of criteria weights in the AHP

The matrix A is the result of the pairwise comparison of 8 criteria (ArcGIS-for-desktop). After the formation of the comparison matrix, which was executed in expAt 2.0. (http://www.arcgis.com/home/item.html?id=bb3521d775c94b28b69a10cd184b7c1f, nd), the weights of criteria (wi) are calculated for each criterion. The comparison matrix and the weights of criteria are given in Table 4.

Table 4 – Comparison matrix and the weights of criteria
Таблица 4 – Сопоставительная матрица и весовой коэффициент
Tabela 4 – Matrica poređenja i težine kriterijuma

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	w_i
C_1	1	3	4	1/2	2	4	8	6	0.25
C_2	1/3	1	2	1/2	1	2	3	2	0.11
C_3	¼	½	1	1/6	1/5	1	3	2	0.06
C_4	2	2	6	1	3	4	6	2	0.29
C_5	½	1	5	1/3	1	3	4	2	0.14
C_6	¼	½	1	¼	1/3	1	1/2	2	0.06
C_7	1/8	1/3	1/3	1/6	¼	2	1	1/3	0.04
C_8	1/6	1/2	1/2	¼	1/2	1/2	3	1	0.05

Taking the weights into consideration, it can be concluded that the distance from the surface flows is the most important criterion; on the other hand, the distance from the road network, altitude, slope and aspect have a minimum weight because they do not significantly affect the environment, but since they determine the cost of construction, they are taken into account.

The value of the consistency ratio CR = 0.062 was determined on the basis of equation (1). The value CR ≤ 0.1 points to the overall consistency of the comparison matrix.

The generation of a landfill suitability map based on the eight criteria was accomplished in the GIS environment. The final realization used the Weighted Linear Combination (WLC) that is integrated into ArcGIS 10.2. (http://www.esri.com/software/arcgis/arcgis-for-desktop), in accordance with equation (2). As a result of multiplying weighted criteria obtained as a result of the AHP, with a cell score of each criterion, the final forest fire risk map is generated. The suitability index is classified into five classes: restricted area, low, moderate, high and very high suitability (Figure 3).

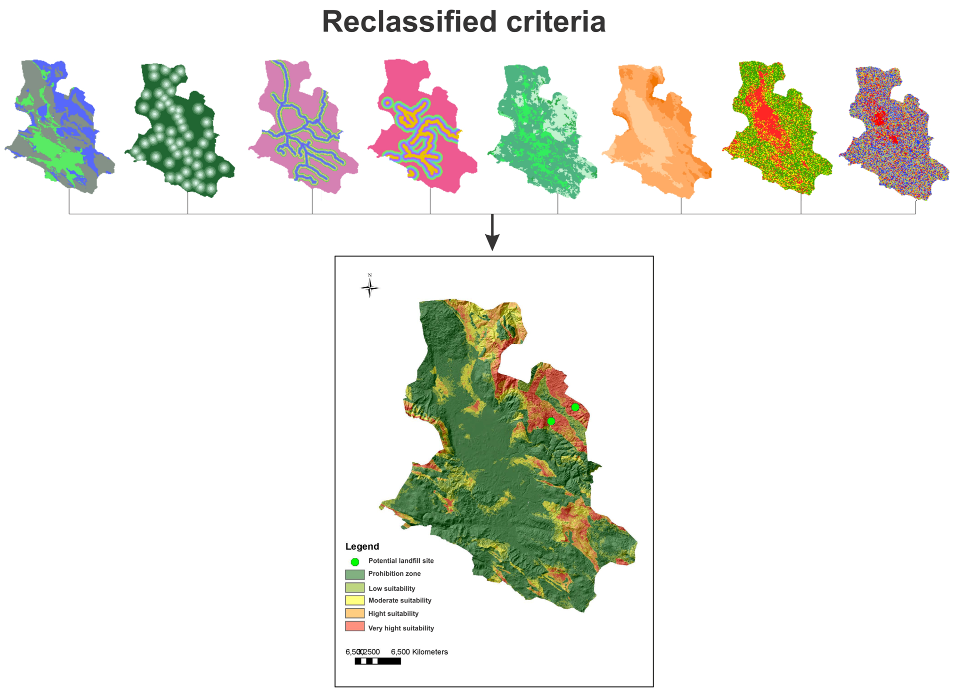

Figure 3 – Potential locations for landfills in the Municipality of Nevesinje
Рис. 3 – Карта потенциальных участков для обустройства свалки, Муниципалитет Невесинье
Slika 3 – Karta potencijalnih lokacija deponija, opština Nevesinje

The analysis of the results shows that 67.0% of the territory belongs to the restricted zone, 11.0% of the territory has low suitability, 6.1% has moderate suitability, 5.9% has high suitability and 10.0% has very high suitability. Two potential sites suitable for the construction of a landfill are proposed. Both belong to the very high suitability zone. The visibility of a landfill from the settlements was also taken into account. The visibility was determined using the Viewshed tools.

However, before the final decision is made, it is necessary to visit the site as well as to analyze the ownership of the land, the land price and the opinion of the public and community structures.

Conclusion

Landfills are treated as objects of non-economic activities, while a landfill site selection is a special task in terms of the use of building plots and their price.

In this paper, the selection of sites suitable for the construction of a landfill was carried out using GIS and the AHP. GIS was used for spatial statistics and grouping the most suitable areas, as well as for managing large amounts of spatial data collected from various resources. On the other hand, the AHP allows solving complex problems which depend on many factors. The paper defines two potential locations for the construction of a landfill in the Municipality of Nevesinje. The analysis was based on eight criteria: geology, distance from settlements, distance from road networks, distance from surface water bodies, vegetation, slope, altitude and aspect. Larger weights are assigned to environmental parameters (geology, distance from surface flows, etc.). The study identifies five suitable zones out of which 67.0% of the territory belongs to the restricted areas, 11.0% has low suitability, 6.1% has moderate suitability, 5.9% has high suitability and 10.0% has very high suitability.

The results can be used as a model for the landfill site selection in an area with similar characteristics, because it provides to the decision-maker an analysis and support in solving problems related to waste management. Although a comprehensive analysis of the given factors for landfill site selection requires a lot of time and funds, the authors recommend its implementation. In this case, in order to comprehensively protect the environment and human health, it would be necessary to conduct the analysis of environmental risk assessment.

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МЕТОДЫ ГИС ТЕХНОЛОГИИ АНАЛИТИЧЕСКОГО ИЕРАРХИЧЕСКОГО ПРОЦЕССА ПРИ ОПРЕДЕЛЕНИИ МЕСТОПОЛОЖЕНИЯ СВАЛОК

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ОБЛАСТЬ: геонауки
ВИД СТАТЬИ: оригинальная научная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

Свалки наиболее распространенный вид размещения отходов. Выбор участка для размещения свалки представляет собой длительный и тщательный процесс, требующий выполнения целого ряда мероприятий при соблюдении законодательных актов, экологических, экономических и социальных нормативов и стандартов, с целью снижения негативного воздействия на окружающую среду. В данной статье приведены испытанные местности на территории муниципалитета Невисинье (Республика Сербская) для обустройства свалок. Геомониторинг местности проводился методом аналитического иерархического процесса (АНР) при помощи ГИС технологии. Анализ испытуемой местности включал следующие критерии: геологические изыскания, безопасное расстояние от населенных пунктов, безопасное расстояние от путей сообщения, безопасное расстояние от водоемов, вегетация, склоны и оползни, высота над уровнем моря и экспозиция на местности.

На основании примененного АНР метода определены относительные весовые коэффициенты каждого из критериев, а их линейная соотнесенность с рангом каждой ячейки определяет весовой коэффициент благоприятности. Весовой коэффициент благоприятности распределен следующим образом: 67,0 % запрещенная местность, 11,0% несоответствующая местность, 6,1% умеренная местность, 5,9% благоприятная местность и 10% наиболее благоприятная местность. На основании данных исследований было предложено два участка для обустройства свалки, но для окончательного согласования необходимо провести разведочные исследования и анализ дополнительных параметров.

Ключевые слова: *свалка, местоположение, АНР, ГИС.*

ODREĐIVANJE LOKACIJE DEPONIJE PRIMENOM GIS TEHNOLOGIJE I ANALITIČKOG HIJERARHIJSKOG PROCESA

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OBLAST: geonauke
VRSTA ČLANKA: originalni naučni članak
JEZIK ČLANKA: engleski

Sažetak:

Deponije su jedan od najčešćih načina odlaganja otpada. Izbor lokacije deponije je komplikovan i dug proces koji uključuje zakonske regulative, ekološke, ekonomske i socijalne parametre radi smanjenja negativnog uticaja na životnu sredinu. Izbor test-područja pogodne lokacije za deponiju na području opštine Nevesinje (Republika Srpska) izvršen je primenom analitičkog hijerarhijskog procesa (AHP) i GIS tehnologije. Analizirano je 8 kriterijuma: geologija, udaljenost od naselja, udaljenost od putne mreže, udaljenost od reka, vegetacija, nagiba terena, nadmorske visine i ekspozicija.

Primenom AHP definisani su relativni težinski faktori za svaki kriterijum, a njihovom linearnom kombinacijom s rangom svake ćelije određen je indeks pogodnosti. On je reklasifikovan u pet klasa pogodnosti, pri čemu 67,0% prostora pripada području zabrane, 11,0% niske pogodnosti, 6,1% umerene pogodnosti, 5,9% visoke pogodnosti i 10,0% području veoma visoke pogodnosti. Predložene su dve potencijalne lokacije za izgradnju deponije, ali pre donošenja konačne odluke potrebno je izvršiti obilazak lokacije i analizirati dodatne parametre.

Ključne reči: *deponija, izbor lokacije, AHP, GIS.*

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ПРЕГЛЕДНИ ЧЛАНЦИ
ОБОЗОРНЫЕ СТАТЬИ
REVIEW PAPERS

AERODYNAMIC AIRFOIL AT CRITICAL ANGLES OF ATTACK

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Summary:

Aircraft construction experts must not neglect the behavior of aircraft in extreme or closely extreme flight conditions, such as flights at critical angles of attack, where a normal flight can be easily converted into a stall.

This paper highlights the essential factors that influence the behavior of aircraft in flight at critical angles of attack. Based on the available experimental results and estimations, the performances of airfoils were analysed depending on air flow conditions (categorized according to Mach and Reynolds numbers), airfoil shapes, dynamics of the transition of angles of attack, description of the flow around airfoils with increasing the angle of attack upon reaching a critical value, and the effect of roughness of airfoil surfaces at critical angles of attack.

The paper gives a physical interpretation of a lift decrease and a stall. It minutely describes the origin of flow separation and categorizes airfoil sections by type of separation and their behavior during the flow at the critical angle of attack.

Based on modern aerodynamics, this paper aims to show and explain the issues and the most important characteristics of the flow past the body at critical angles of attack and give practical recommendations for airfoil design. As such, it may be of interest to pilots and engineers as well as to educational and research institutions.

Key words: *aerodynamic, performance of airfoils, fluid dynamics, airfoil shape, critical angles of attack.*

Introduction

A value of the lifting force of the wing (of a body in flow) obtained at the moment when further increase of the angle of attack (α) does not increase it any more is called the maximum lift force of the body for given flow conditions (Gretchikhin, 2014). The angle of attack at which separation of the laminar flow occurs on the curverepresents the point of falling of the C_L/α curve angle (chart C_L/α Figure1).

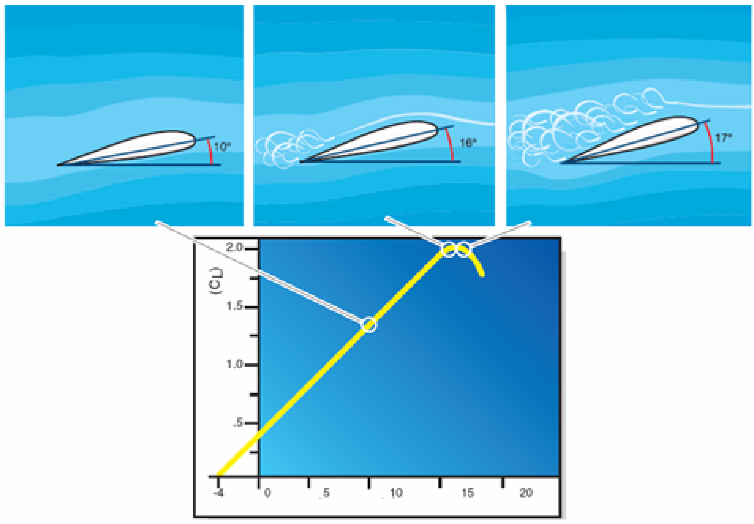

Figure 1 – Change of the lift coefficient C_L when increasing the angle of attack α
Рис. 1 – Изменение коэффициента подъемной силы C_L при увеличении угла атаки α
Slika 1 – Promena koeficijenta uzgona C_L sa povećanjem napadnog ugla α

A value of the angle attack at which the lift coefficient has the maximum value represents the angle of the maximum lift. A further increase of the attack angle causes that the lift force decreases slowly in the beginning, then more steeply. For certain values of the angle of attack ($\alpha_{кр}$), the lift force is lost.

The maximum lift depends on various factors:

- Airfoil shape (of a body in flow);
- The flow conditions (modeled by Reynolds and Mach numbers);
- The shape of the wing (of a body in flow), slenderness, the position of the wings in relation to the flow and the aircraft fuselage (the angle of the arrow, curl wings);
- Aerodynamic additions to wings;
- The engine; and
- Flight dynamics of the body.

The value of the maximum lift coefficientis a complex function that depends on the geometric size of the airfoiland the Reynolds number; therefore, it cannot be calculated analytically. The wind tunnel testing has led to the empirical equations that apply to a specific area of the Reynolds number, so that usual airfoils for approximate calculations can be determined from the equation:

$$C_{z\max} = 1.73 - 2.4\left[1 - 14\left(\frac{d}{l}\right)_{\max} + 50\left(\frac{d}{l}\right)^2\right] + 2\left(\frac{c}{l}\right)_{\max}$$

The above formula applies to the value of Re=3·10^6, while for other values of the Reynolds number it is necessary to make corrections.

An approximate value of the critical angle of attack is obtained from the equation:

$$a_{\max} = \left(11 + a_n\right) + 50\left(\frac{d}{l}\right)_{\max} + 70\left(\frac{c}{l}\right)_{\max}$$

As shown in Figure 2, C_{lx} is from 1.5 to 1.6, i.e. less than 10% of the theoretically possible values (Cone,1985).

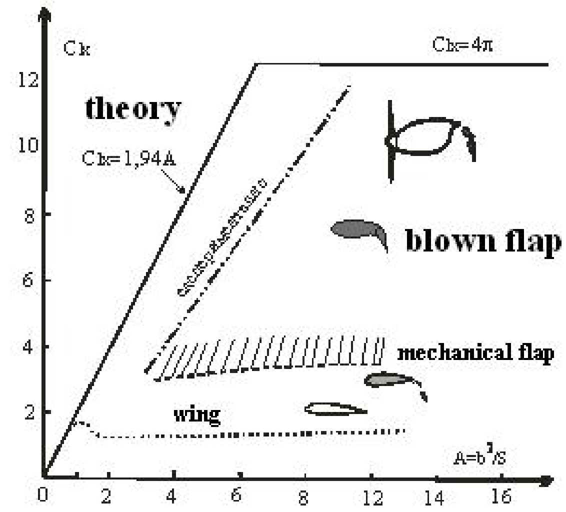

Figure 2 – Potential maximum lift force coefficient
Рис. 2 – Потенциальное максимальное значение коэффициента подъемной силы
Slika 2 – Potencijalni maksimalni koeficijent uzgona

With aerodynamic accessories (slats and flaps) and an additional impact of jet (engine), the values of about 30% of the theoretical value are obtained.

The physical interpretation of a stall

An increase in the angle of attack observed along the airfoil leads to the following:

- Large vacuum near the leading edge;
- Strong positive pressure gradient between the negative peak and the trailing edge;
- Increase of the boundary layer along the upper side of the airfoil.

An increase of the angle of attack of the flow at the airfoil cross-section leads to two critical points in the stream where the separation of flow can be expected:

1. At the leading edge, where a streamline must flow around the attack "nose", which corresponds to a loss of momentum;
2. In the vicinity of the trailing edge, where there is a noticeable increase in the thickness of the boundary layer.

The loss of lift due to the separation of flow occurs in one of these points or at both points at the same time. In Figure 3, the CL-α diagram (Kostić, 2010) shows three specific ways of flow separation.

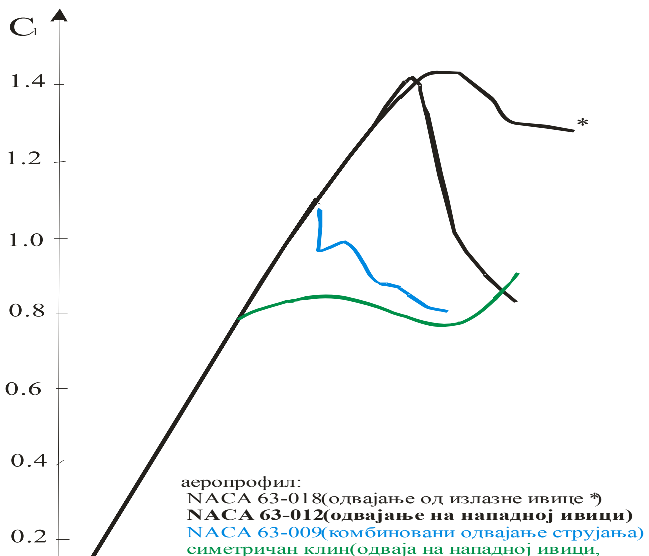

Figure 3 – Types of the separation flow of the A-profile, *Re*= 5.8 • 10^6
Рис. 3 – Виды срыва потока на А-профиле,Re=5,8• 10^6
Slika 3 – Tipovi otcepljenja strujanja A-profila, *Re*=5,8•10^6

The selection included the airfoils whose CL-α curve values coincide up to α≈60, after which there is a characteristic discrepancy.

Separation from the leading edge - elongated bubble shapes

Separation from the leading edge isgradually formed on thinner airfoils with relatively sharp leading edges, as a form of an elongated laminar separation bubble;

Adouble-fold curve, characteristic for flow separation at the leading edge in a shape ofelongated bubbles, ca be noticed. Lift rises, almost linearly, then gently falls and remains constant for values $\alpha \approx 8.5\text{-}10^{\circ}$, then the lift force continues to decline slightly, followed by an increase.

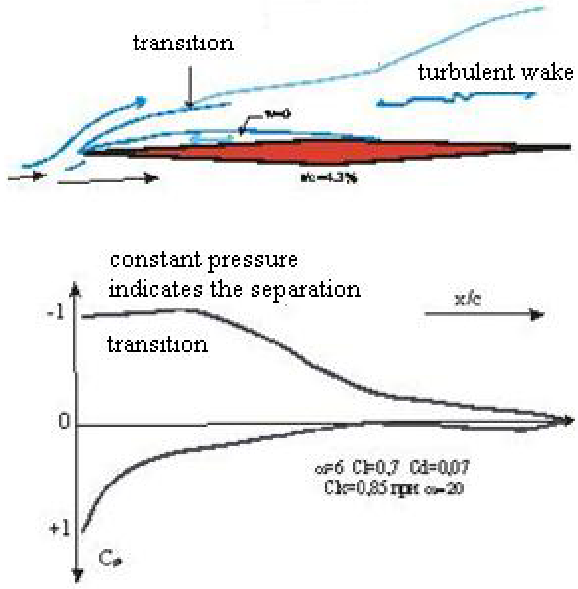

Figure 4 – Example of stalling a thin, sharp airfoil
Рис. 4 – Пример сваливания тонкого стреловидногокрыла
Slika 4 – Primer prevlačenja tankog, oštrog aeroprofila

The reason for this behavior of airfoils lies in the short distance between the stagnation point (when α>0, it is located on the underside) and the leading edge, so that the boundary layer in this zone is very thin.

The Reynolds number is low for the given case.We take into account the existence of a strong negative pressure gradient between the stagnation point (where Cp=+1) and the leading edge (where probably Cp=-10). The airflow over the sharp leading edge is laminar in the boundary layer until abrupt flow separation (McCullough, 1955). Namely, the usual transition to turbulent flow inside the bubble is not typical for this case. After flow separation, as shown in Figure 4, the boundary layer next to a newly formed bubble becomes significant space created by mixing with the fluid within the separation bubble. The result of this mixing is the reduced thickness of the separation bubble as the flow moves away from the leading edge to the place where it again joins the boundary layer of the upper airfoil.

The presence of bubbles is recognized through pressure distribution along the airfoil, Figure 4, presenting a constant area of the negative pressure coefficient, where, if the bubble did not exist, there would occur a sudden change in pressure (peak on the curve), which in this case does not exist.

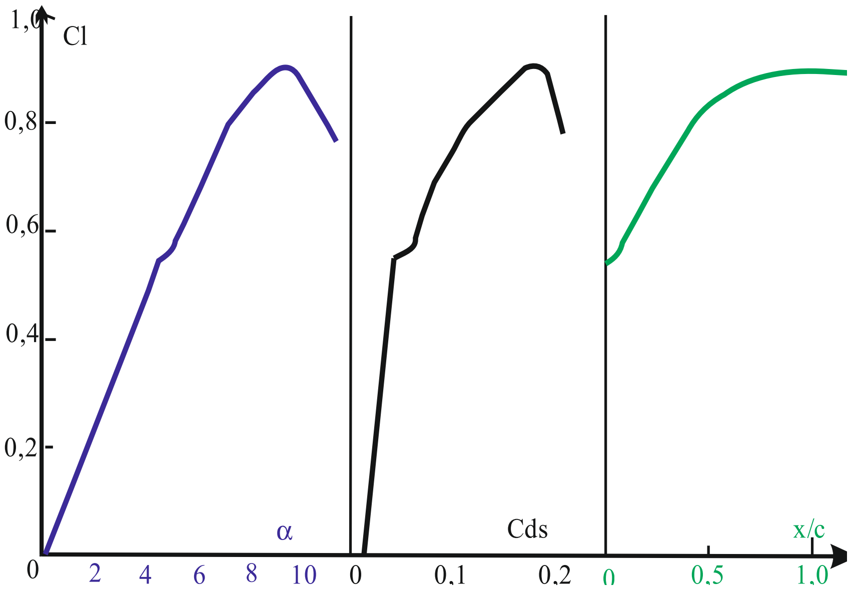

Figure 5 – Lift, drag and the separation bubble characteristic for the NACA 64A006 airfoil
a) Lift with discontinuity at C_L=0.56
b) Section drag showing sudden increase at C_L=0.56
c) Length of the separation bubble from the leading edge
Рис. 5 – Подъемная сила, сопротивление и область отрыва
a) Разрыв непрерывности подъемной силы при C_L=0,56
b) Резкий скачок коэффициента сопротивления при C_L=0,56
c) Длина отрывного пузыря упередней кромки
Slika 5 – Uzgon, otpori, separacioni mehur za aeroprofil NACA 64A006
a) Diskontinuitet uzgona pri C_L=0,56
b) Naglo povećanje koeficijenta otpora pri C_L=0,56
c) Dužina mehura otcepljenja od napadne ivice

In the diagram CL-α, CD, x/c (bubble) for the NACA 64A006 airfoil shown in Figure 5, it can be noted that in the section ≈6% x/c for CL=0.56 acurve discontinuity appears, showing the moment of the creation of initial separation and a bubble, which is reflected in a sudden increase of the drag coefficient.

With a further increase of the angle of attack, the area affected by the separation bubble grows proportionally to a critical moment which corresponds to the maximum lift, after which it extends along the entire length of the upper airfoil, followed by the reduction in lift and transit to a stall. In the previous case, the separate bubble extends to 60% of the airfoil chord (*x/c*), then the increasing of α leads to the 75% of the airfoil chord (*x/c*).

Separation from the leading edge - short bubble shapes

Short bubble shapes occur as sudden separation when flow passes airfoils with a sharp leading edge, or at flow past a low curved airfoil;

For airfoils characterized by an abrupt onset of a small flow bubble, it is characteristic, as shown in the diagram for the NACA 63-012 airfoil (Figure 3), that the lift force increases almost linearly up to the maximum and then falls sharply.

Separation from the trailing edge

Separation from the trailing edge is characterized by slight gradual separation. It starts from the trailing edge and moves towards the leading edge, proportionally to the increase of the angle of attack. The NACA 63-018 airfiol, Figure 3, with a rounded leading edge, is a typical representative of the airfoil group in which separation occurs at the trailing edge. It is characterized by an almost linear increase of lift, then a gradual transition to lift loss and complete flow separation. The length at which a separation bubble is formed depends primarily on the airfoil shape. In the case of flow past the airfoil, Figure 4, the length extends up to 60% of the airfoil chord, while with further increase of the angle of attack separation occurs starting from the airfoil trailing edge. A stall occurs after the moment when the separation begins from the trailing edge and comes to a point of 25% of the leading edge.

For airfoils used for subsonic flows, the length of the separation bubble varies from 15% to 25% of the length of the airfoil chord.

If a rounded leading edge is used, and the airfoil thickness and curvature are increased, the risk of separation bubble formation on the leading edge is eliminated.

The next critical zone for flow separation due to an increased angle of attack is near the trailing edge.

Figure 6 (Pinkerton, 1996) introduces the distribution of pressure along the airfoil at the time immediately prior to reaching the maximum coefficient of lift (C_{LX}).

The distribution of the pressure coefficient depends on the shape of the airfoil, Reynolds number, angle of attack, relative thickness, curvature of the center line and the relative curvature of the leading airfoil edge.

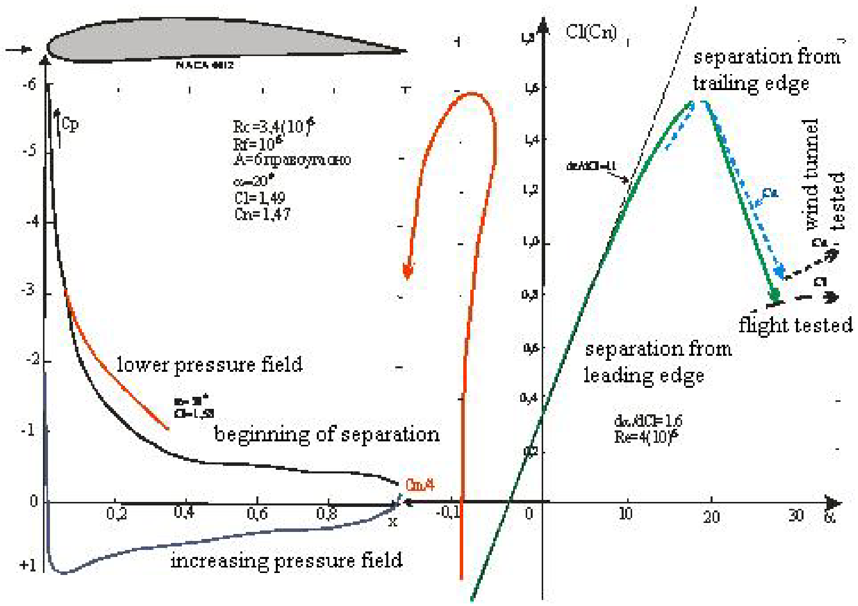

Figure 6 – Characteristics of the lift force of the NACA 4412 airfoil and the distribution of C_L, C_N, Cm
Рис. 6 – Характеристики подъемной силы профиля крыла NACA 4412 и распределение C_L, C_N, Cm
Slika 6 – Karakteristike uzgona aeroprofila NACA 4412 i raspodela*C_L,C_N,Cm*

Let us consider the values of the local maximum speed using the equation:

$$w/V \approx 1 + 2t/c + 0.2\, C_L / (r/t) \qquad (3)$$

where r/t is the ratio of the radius of the leading edge and the airfoil thickness (typically between 0.5 and 2.0 t/c). A possible maximum local velocity w, the maximum dynamic pressure q and the minimum pressure coefficient can be obtained from this equation.

Both parts of the right side of equation (3) produce a positive pressure gradient while approaching the trailing edge of the airfoil. Under the influence of this gradient, the boundary layer increases significantly and the trailing edge has a total thickness of δ, which can be written as:

$$\delta/c = 5C_f + k(C_L)^n$$

where $C_f \approx 0.03$ is the coefficient of friction resistance, n=2, the coefficient *k* of the order of 10.

After the boundary layer thickening, it reaches the critical moment when its movement against pressure cannot continue and flow separation occurs in the accumulated boundary layer. As a result, there has been a cessation of circulation increase with the increase of the angle of attack and the lift reaches its maximum.

Figure 6 shows the NACA 4412 airfoil in the C_L, C_m-α diagram. Before reaching its maximum, the lift coefficient diagram diverges from the straight line, initiating flow separation from the trailing edge. An increase of the angle of attack through C_{LX} results in a gradual lift decrease, without discontinuity, down to the angle of attack after which a complete separation flow occurs, which corresponds to the scenario when the separation from the trailing edge is extended to the leading edge.

Airfoils with circular sections

Let us consider the behavioral characteristics of the lift of the airfoil section with a circular shape, with a curvature of 10%, for three values of the Reynolds number, shown in Figure 7 (Kostić, 2010).

When the airfoil lower sideis flat, the degree of curvature is equal to 0.5 of the airfoil slenderness. The maximum thickness located at 50% of the length of the chord gives airfoils with the prominent wedge-shaped trailing edge at the site of potential vacum, which easily leads to initial separation. Symmetric thickening with the maximum curvature in the middle of the airfoil, combined on the side with lower pressure, increases sensitivity towards separation flow while approaching the trailing edge.

It can be noticed that, under the sameflow conditions, the behavior of the airfoil depends on the Reynolds number, therefore:

1. When the value of Re=10^5, the laminar type of separation occurs. The point with the minimum pressure corresponds to the half of the airfoil tendon. Under these conditions, the minimum drag coefficient is 0.02, which confirms the separation of flow.

2. When the value of Re=$3{\cdot}10^5$, at the angle of attack corresponding to the lift coefficient of 0.575, which is identical to the theoretical C_{Lsym}=0.115(f/c)%.

The value of the drag coefficient (C_{DS}=0.008=min) clearly confirms that this is a completely clean, pressed flow, which represents in this case optimum.

Increasing the Reynolds number over Re=$3{\cdot}10^5$ gradually reduces the lift coefficient for a minimum resistance value and for Re=$5{\cdot}10^6$ the lift coefficient is C_{LO}=0.46. In the separation layer, turbulent flowappears.

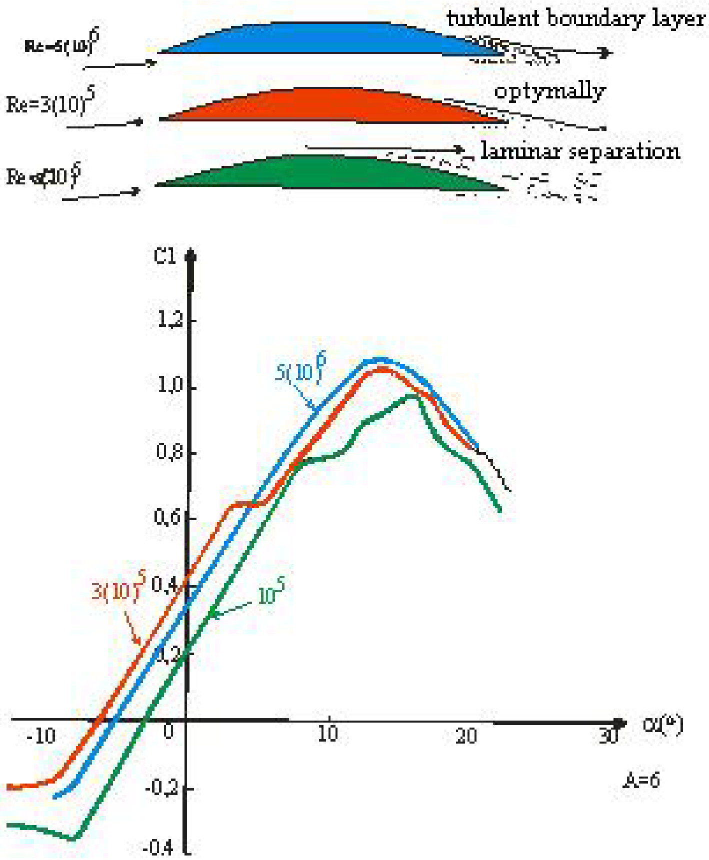

Figure 7 – Characteristics of lift and the mechanism of stalling an airfoil with 10% of curvature
Рис. 7 – Характеристики подъемной силы и механизм обтекания крыла с 10% -ой кривизной профиля
Slika 7 – Karakteristike uzgona i mehanizam prevlačenja aeroprofila sa 10% zakrivljenosti

For the observed cases, Figure 7, the graph of the lift coefficient decreases in all three cases. The angle of zero lift at *Re*=10^5h as a value of -3^0; while an increase of the Reynolds number to *Re*=$3\cdot10^5$ results in a decrease of the angle of zero liftto the value of -6^0. However, at the value of *Re*=$5\cdot10^6$, the angle of zero lift increases to -5^0.

This variation of the angle of zero lift value depends on the coefficient of the resistance to friction from the lower value of 10^5 for laminar flow separation, through the part with turbulent separation for which the minimum drag coefficient (optimum) is valid, to the value where turbulent separation is dominant, i.e. a value of $5\cdot10^6$.

The curvature of the leading edge of the observed airfoils is possible to reduce the drag coefficient, so the curvature of r/c≈1-2% gives a reduction in the drag coefficient of C_{DS}=0.038 atC_{DS}=0.017 for $Re=4\cdot10^6$.

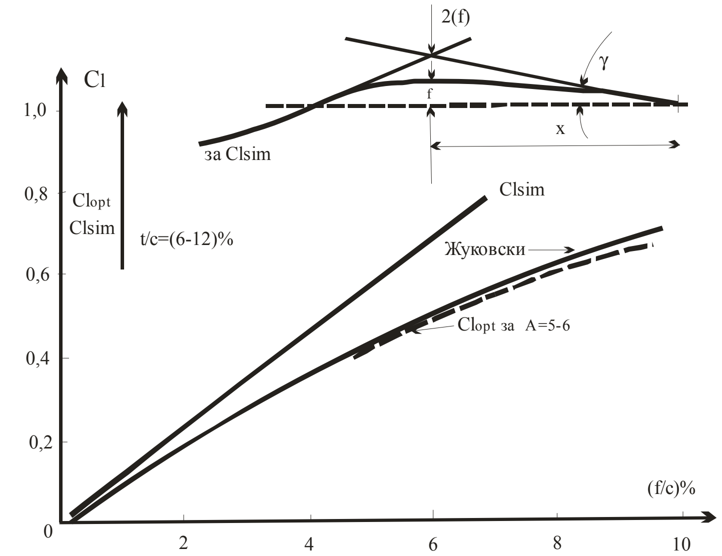

Figure 8 – Optimum lift coefficient as a function of the airfoil camber, t/c = 6-12%
Рис. 8 – Оптимальный коэффициент подъемной силы хорды профиля крыла, t/c=6-12%
Slika 8 – Optimalni koeficijenti uzgona u funkciji srednje linije aeroprofila, t/c=6-12%

The diagram in Figure 8 shows the influence of the airfoil camberand the position of the airfoil maximum thickness to the values of the lift coefficient. The diagram is obtained using the equation C_{Lsym}=0.115(*f/c*)% and compared with the graphs obtained by equations experiments, where it can be concluded that the optimal position of the maximum thickness of subsonic symmetric airfoils is between 30-40% of the mean airfoil chord.

Maximum lift depending on the shape and *Re*

Changing the boundary layer and the drag coefficient is directly dependent on the Reynolds number and roughness of the flowsurface. The loss of lift of flow around the body directly depends on the body's shape. The transition from the laminar flow of the boundary layer into the turbulent one can be caused by an external factor (turbulence of the flow field, turbulence inside the wind tunnel, etc.) or by increased surface roughness of the leading airfoiledge.

C_{LX} *as a function of the shape of the leading edge*

Figure 9 shows the dependence of the maximum lift coefficient (C_{Lx}) on the leading edge radius (r/c) of symmetric airfoils.

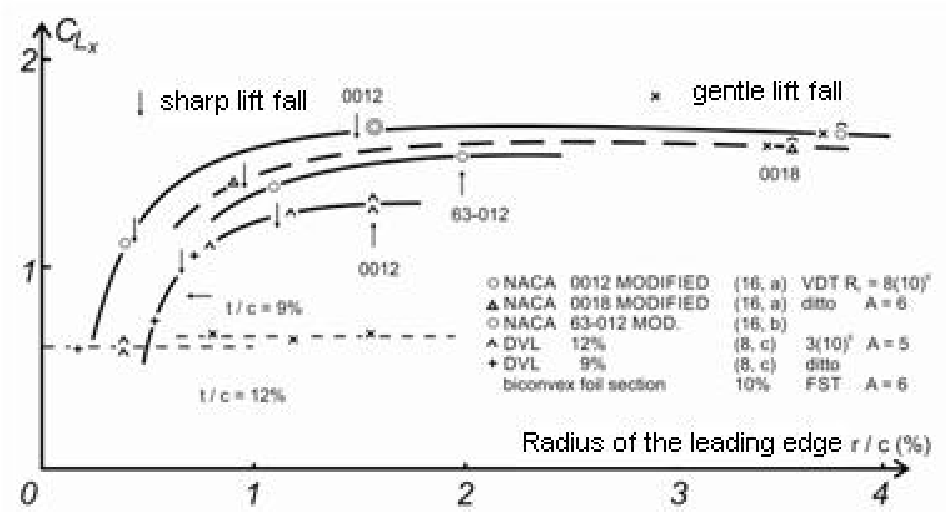

Figure 9 – Maximum lift of symmetric profiles, depending on the leading edge radius r/c
Рис. 9 – Максимальная подъемная сила симитричного профиля крыла в зависимости от радиуса закругления его передней кромкиr/c
Slika 9 – Maksimalni uzgon simetričnog aerodinamičkog profila, u zavisnosti od radijusa napadne ivice r/c

The radius which produces the largest lift coefficient is between 1.5 and 2.0% of the tendon (*r/c*=1.5-2.0%) for the airfoils with *t/c*=6-18%.

For NACA 0012, NACA 0018 and NACA 63-012 airfoils shown in Figure 10 (Hoerner, Borst, 1985), it is evident that, with an increase in the *r/c*, the value of C_{LX} grows. From a value of *r/c>1.6%, the* gradient of the curve decreases.

It should be considered that, as the curvature of the leading edge of the airfoils increases, the drag coefficient also increases, as shown in Figure 10 (Kostić, 2010), which displays the values of C_L and C_D for the airfoils of relative thickness of *t/c=6%* and *r/c=0.81%* and *r/c=0.24%* depending on the change in the angle of attack. It is noticeable that the drag coefficient increases as the angle of attack increases.

Airfoils with rounded leading edges have a greater coefficient of lift and a lower drag coefficient at the same angles of attack, so it is only for $\alpha \approx 18^{o}$ that the ratio is $C_L / C_D < 1$.

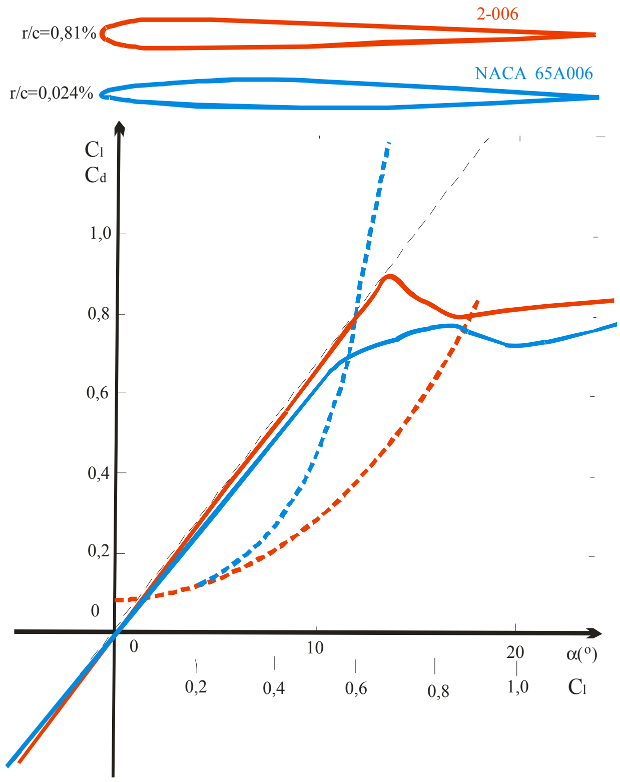

Figure 10 – Lift and drag t/c = 6% of airfoilswith different leading edges, Re = 5 · 10^5

Рис. 10 – Подъемная сила и сопротивление t/c = 6% профиля крыла с различными передними кромками, Re=5·10^5

Slika 10 – Uzgon i otpor t/c=6% aeroprofila različitih napadnih ivica, Re=5·10^5

It is noticeable that the values of the C_{Dmin} are of approximately same values, and that flow separation at lower values of the angle of attack has resulted in a rapid increase of the drag coefficient for the airfoil with a sharper leading edge.

The mechanism of separation of flow around a thin airfoil can be considered the same as the one in airfoils with sharp leading edges, especially for the values of $Re<10^5$ (von Karman, 2001).

Figure 11 shows the dependence of the curvature of the leading edge of the airfoil (*r/c*) and *Re*. It can be seen that the methods of flow separation can be grouped depending on the values (*r/c*) and *Re*. For the curvature of the leading edge from 0.25% to 1.60%, it can be concluded that, at $Re<10^6$, separation flow corresponds to the model of thin airfoil separation, while for $Re>2\cdot 10^6$ separation flow corresponds to the model of thin airfoil separation and trailing edge separation.

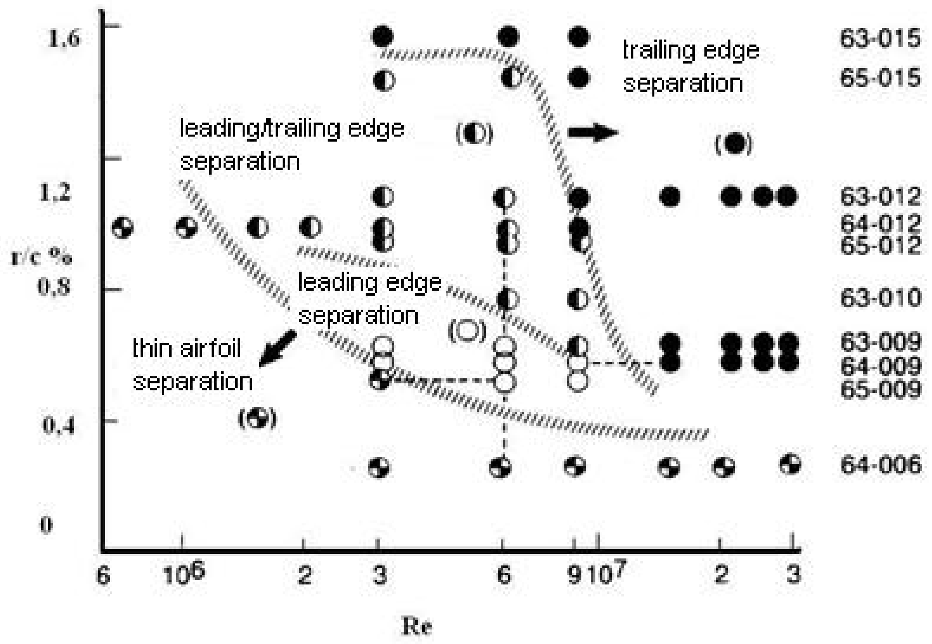

Figure 11 – Stall domains due to the leading edge radius r/c and Re
Рис. 11 – Модель срыва потока в зависимости от закругленности передней кромки r/c и значения Re
Slika 11 – Model otcepljenja strujanja u zavisnosti od zaobljenosti napadne ivice r/c i vrednosti Re

A typical example of application of sharp leading edges is seen when creating ship propellers, where the value of the Reynolds number is below the critical value of $Re<10^5$.

The curvature of the airfoil leading edge sectors

Also, C_{LX} is a function of the curvature of the airfoil leading edge sector (camber line of the airfoil), *f/c*, and the shape of the leading edge, i.e. *r/c*. Around the thin airfoil leading edge, a flat plate, flow bends from the lower side through the leading edge to the upper side. At larger Reynolds numbers, laminar separation and the bubble effect of the boundary layer can be reduced.

Figure 12 shows the change in the lift coefficient of airfoils with sharp leading edges for different values of the curvature of the center line of the airfoil in the conditions of flow of similar Reynolds numbers.

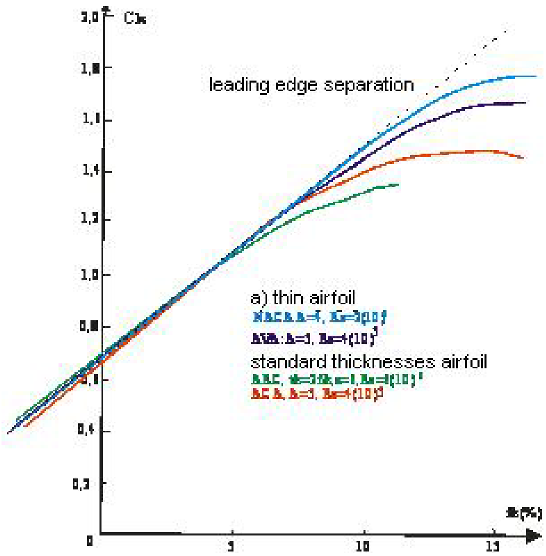

Figure 12 – The maximum lift coefficient of an airfoil with a sharp leading edge, as a function of the degree of curvature of the camber line of the airfoil
Рис. 12 – Максимальный коэффициент подъемной силы крыла с острой передней кромкой, как функция степени округленности средней линии профиля
Slika 12 – Maksimalni koeficijent uzgona aeroprofila oštre napadne ivice, kao funkcija stepena zakrivljenosti srednje linije aeroprofila

It can be said that there is no difference in the examples shown in terms of the location of the maximum curvature of the camber line of the airfoil for the maximum lift between 30% and 50% of the chords of the airfoil. This is illustrated by graphically presenting the $C_{LX}/(f/c)$ relations, obtained by testing airfoils in the wind tunnel, (Doenhoff, 2015) Figure 13.

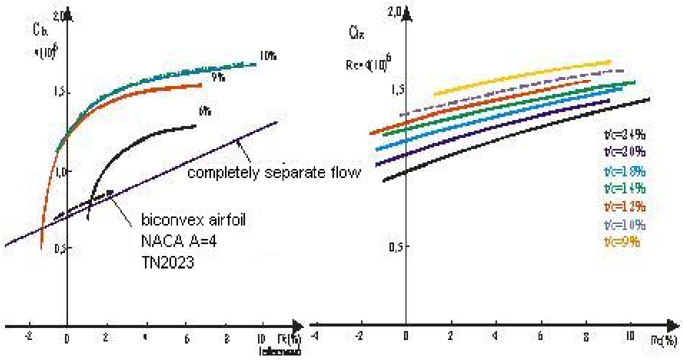

Figure 13 – The maximum lift coefficient, relative maximum lift coefficient, the relative thickness of airfoil 6-9% and 12-24% for Re, f = 4 • 10^6
Рис. 13 – Максимальная подъемная сила, относительный максимальный коэффициент относительной толщины профиля6-9% и 12-24%, для Re, f = 4 • 10^6
Slika 13 – Maksimalni koeficijent uzgona, relativni maksimalni koeficijent uzgona, relativne debljine aeroprofila 6-9% i 12-24%, za Re,f = 4 • 10^6

After the adjustment to A = 5 in accordance with the equation (Kostić, 2010):

$(f/c)\% \approx (1.4+0.2)C_L = 1.6\% C_L$

the characteristics of thin airfoils, with t/c=6 and 9%, are shown in Figure 13, which shows that, for the degree of curvature of the camber line of the airfoil between -1% and +1, the maximum lift coefficient corresponds to the critical angle of attack of separation flow (of 30^0).

Practical use of thin airfoils and the curvature of sections in aviation is limited by structural conditions (providing the necessary wing capacity for the required airfoil thickness), but they are applicable in the construction of turbine blades and fan blades.

The coefficients of the maximum lift decrease with the increase of the maximum relative thickness of airfoils of 12% or more are shown in Figure 13. The maximum lift coefficients grow as a function of a relative airfoil curvature, to the airfoils with the highest tested curvatures, those of 10%.

The curvature of the nose (leading sections of airfoils)

The study of the NACA 63012 airfoil, Figure 14, at $Re=5(10)^6$ and M=0.18, leads to the conclusion that at C_{Lx} = 1.36 separation flow occurs suddenly, with strong shocks and shaking for angles corresponding to the values immediately prior to the occurrence of separation. This can also be anticipated by observing the diagram in Figure 8.

Increasing the radius of the leading edge nose of 1.1% to 2% of the length of the camber aerodynamic chord, makes C_{Lx}grow to a value of 1.50, while a sudden stall is still present.

To avoid a sudden stall, the airfoil leading section was folded, Figure 14. The values of C_{Lx} grow again, but a sudden stall is still present. Separation occurs following the model of a thin airfoil with a separation bubble which does not change from the initial shape to the moment when it suddenly increases and extends towards the trailing edge. The distribution of the pressure coefficient shows that separation occurs at C_{pmin}=-10.

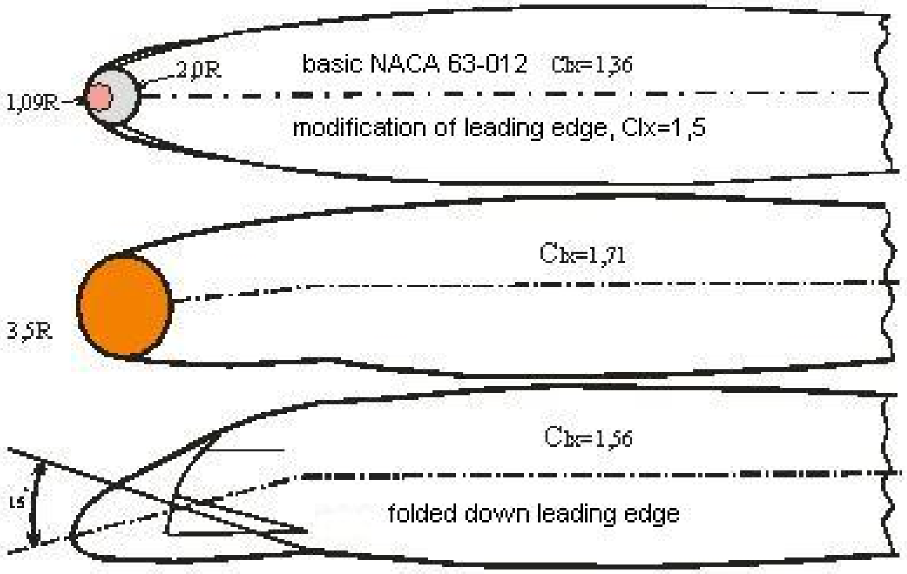

Figure 14 – Modifications to the leading edge, NACA 63-012, Re = 4.9 • 10^6
Рис. 14 – Модификация передней кромки, NACA 63-012, Re= 4,9 • 10^6
Slika 14 – Modifikacije napadne ivice, NACA 63-012, *Re*=4,9 • 10^6

Changing the curvature and the radius of the airfoil leading edge increases the value of the maximum lift approximately, but it does not change the separation mechanism. As a sudden entry intoa stall is unfavorable, it is recommended that a combination of the relative thickness and the airfoil curvature is used to transfer the mechanism of sudden separation occurrence in the attack sector to gradual separation which is a characteristic of the separation from the trailing edge.

The critical Reynolds number

When choosing airfoils (any aerodynamic form), it is important to know the values of the Reynolds number for which they can be used. The critical Reynolds number at which turbulent flow occurs in the boundary flow field of the upper wing surface for thin airfoils is $Re=10^5$, Figure 15 (Kostić, 2010). It is noticeable that airfoils with a smaller curvature have higher values of the critical *Re*with an increase in C_{LX}.

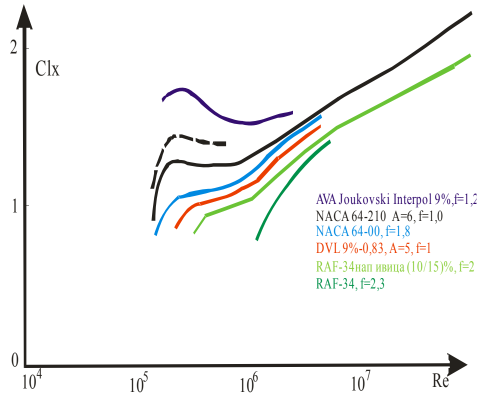

Figure 15 – Maximum lift of rectangular wings as a function of Re, t/c = 8-10%
Рис. 15 – Максимальная подъемная сила правоугольного крыла как функция Re, t/c = 8-10%
Slika 15 – Maksimalni uzgon pravougaonih krila kao funkcija Re, t/c = 8-10%

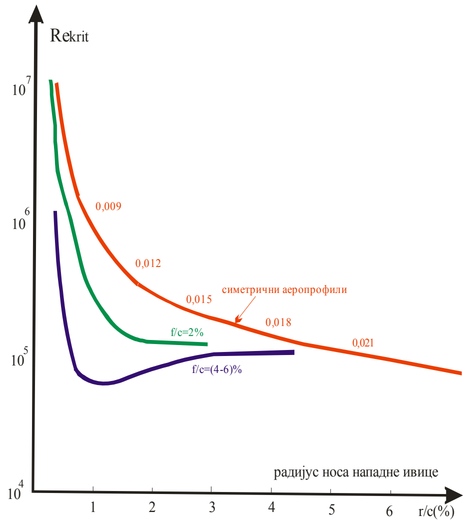

Figure 16 – Critical Re as a function of the radius at the leading edge of the airfoil
Рис. 16 – Критический Re, как функция радиуса закругления передней кромки
Slika 16 – Kritični Re, kao funkcija radijusa napadne ivice

Airfoils such as the NACA 0009 have the same critical way of changing the image of the flow at higher values of Re. The transition from laminar to turbulent flow occurs at ten times higher values of Re than in airfoils with higher relative thickness and the radius of the leading edge.

The radius of the leading edge with the increase decreases the values of the critical Re, as shown in Figure 16 (von Karman, 2001). Airfoils with smaller curvature have a higher value ofthe critical Re with an increase in C_{LX}. For larger Reynolds numbers (10^6 to 10^7), they represent aircraft at low speed during landing and takeoff. TheC_{LX} values are shown in the diagrams above.

The characteristics of airfoils for Reynolds numbers in this range are:

- Flat planes and airfoils with thickness up to 3% have the same approximate maximum lift coefficient, with separation characteristic for thin airfoils;

- Thin airfoils (*t/c*=5-10%) are characterized by increasing C_{LX} as their camber line curvature increases from 0% to 2% (Figure 16). Loss of lift varies from sudden to gradual, depending on the shape and dimensions of the airfoil and on flow past an airfoil conditions;

As it can be seen in Figures 16 and 17, airfoils with a relative thickness between 8 and 12% and the curvature of the camber line between 0% and 2% have a strong tendency towards increasing the maximum lift. Increasing the angle of attack leads to the characteristic flow around the leading edge and to a gentle transition from laminar to turbulent flow.

For airfoils with larger curvature and with apromineently rounded leading edge, flow continues around the leading edge, while the maximum lift coefficient is in a function of the angle of attack at which the laminar boundary layer extends towards the trailing edge. C_{LX} depends on the coefficient of friction along the profile of the upper side of the airfoil. For Reynolds numbers whose value exceeds 10^7, the drag coefficient increases as a result of an increase in the thickness of the boundary layer.

It is noticeable that, depending on the tendencies of C_{LX} change, different types of separation flow occur:

– Airfoils with separation flow of the thin airfoil type are characterized by a fairly constant value of the maximum lift coefficient;

– Airfoils with rapid separation flow tend to increase C_{LX} with an increase of the Reynolds number;

– Airfoils in which the separation bubble is formed towards the airfoil trailing edge with increasing Re grows slowly, so that the maximum lift coefficient decreases for cases with larger curvature of the camber line.

Theoretical analysis

In the early theoretical studies of the boundary layer around the leading edge of the airfoil, the maximum lift was analyzed as a function of the Reynolds number and turbulence flow for thin and curved airfoils.The theory was applicable for Reynolds numbers at which there occurs separation flow characteristic for separation in the leading edge characterized by a laminar separation bubble.

For the case where separation is in relation to the trailing edge, the maximum lift coefficient is the result of the balance between kinetic and pressure forces. Potential energy is represented by an increase in pressure between the point of minimum pressure and the trailing edge. For sections with a pronounced curvature and a rounded leading edge, separation can be determined as a function of the kinetic energy inside the boundary layer. Therefore, while the kinetic energy inside the boundary layer is a function of the Reynolds number and grows in line with the decline in the value of the frictional drag, it can be said that:

$$C_{LX} \approx 1\Big/\sqrt{C_f}\; R_e \sim R_e^{\,n}$$

where n=0.5(1/6)=1/12 and 1/6 is the equivalent ratio during turbulent flow. On the basis of the aforementioned, the above equation can be applied to the value of $R_e<10^7$.

For Reynolds numbers of $4(10)^6$,Figure 17 shows the dependence of the maximum lift coefficient and the relative thickness of the airfoil.

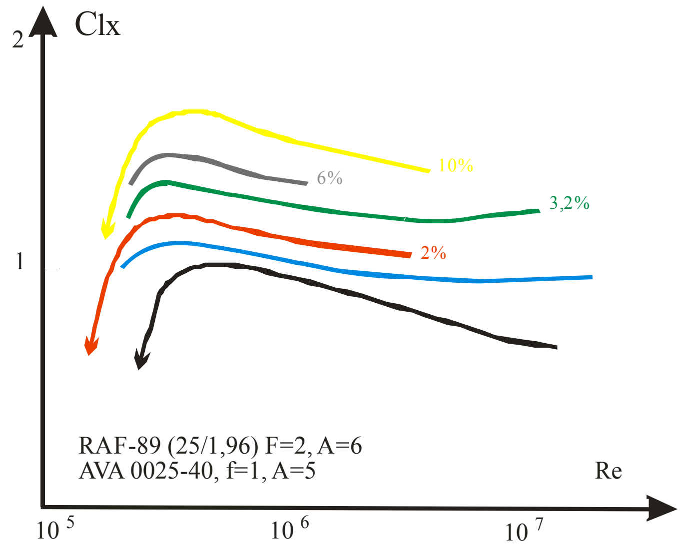

Figure 17 – Airfoil maximum lift, as a function of t/c, at Re = 4 • 10^6
Рис. 17 – Максимальная подъемная сила крыла, как функция t/c, при Re = 4 • 10^6
Slika 17 – Maksimalni uzgon aeroprofila, kao funkcija t/c, pri Re = 4 • 10^6

The maximum lift coefficient is rising sharply in line with the relative curvature of the camber line of the airfoil between 0% and 2%, and for the relative thickness of *t/c*=5-8%. For values of *t/c*over 8% and *f/c*over 4%, the airfoilis characterized by stalling as in thin airfoil. The peaks of the curves can be obtained for values *t/c*≈10%. The source in literature stated that during the experiment, for the values of *t/c*=12%, airfoils showed more efficiency, especially at high subsonic speeds.

Airfoils with *t/c*=(0 до 10)% are most common, and thus most tested, representing a compromise between the aerodynamic and structural demands of an object in an air stream.

Depending on structural needs, the relative thickness of airfoils increases; consequently, the value of *t/c*≈18% is characteristic for the root of the wing of subsonic aircraft. Over the value of *t/c*=18%, the maximum lift coefficient gradually declines; therefore, a stall is gradual and predictable.

Kostić, Č., et al, Aerodynamic airfoil at critical angles of attack, pp. 784–811

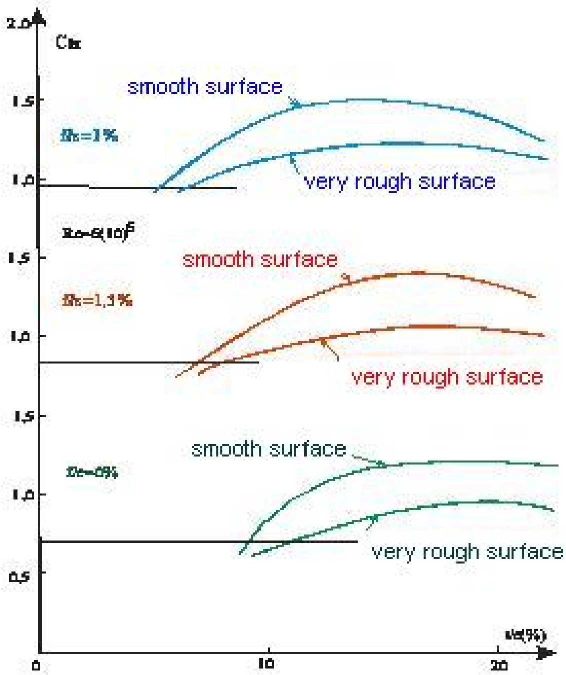

Figure 18 – Maximum lift of airfoils of series 63 and 64, *Re* = 6 • 10^6, as a function of the relative thickness and curvature of the airfoil, for A = 5-6
Рис. 18 – Максимальная подъемная сила крыла серии 63 и 64, Re = 6 • 10^6, как функция толщины аэродинамического профиля и кривизны хорды, для A= 5-6
Slika 18 – Maksimalni uzgon aeroprofila serija 63 i 64, *Re* = 6 • 10^6, kao funkcija relativne debljine aeroprofila i zakrivljenosti srednje aerodinamičke tetive, za A=5-6

High-speed airfoils

Increasing the relative thickness of the airfoil and increasing the camber line lead to the increase of the torque of the resulting aerodynamic forces; therefore,a special attention is given to airfoil sections exposed to high speeds.

The position of the maximum camber is not that important for the maximum lift value, it is important that it is between 0.30 and 0.50 of the aerodynamic chord. On the other hand, the position of the maximum thickness has a significant impact, especially if the radius of the leading edge changes at the same time.

Figure 18 indicates the relation between the maximum lift coefficient and the relative thickness of the airfoils of the NACA airfoil series 63 and 64 and *Re*=6$(10)^6$.

The influence of surface roughness

In theoretical studies of aerodynamic characteristics of an object in an air stream, the object surface is taken to be absolutely smooth. However, in real conditions, there is not an absolutely smooth surface. The following examples will show how uneven airfoil skin influences the occurrence of separation flow, i.e. the value of the maximum lift.

Increasing the roughness of the upper side leads to increased lift for a given angle of attack. On the other hand, increasing the roughness of the lower side reduces the lift for a given angle of attack. The increase of roughness directly affects the thickness of the boundary layer, as well as the flow in it.

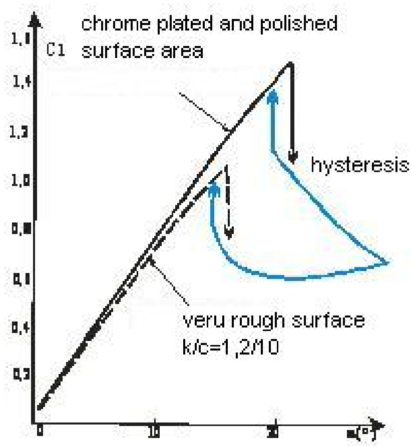

Figure 19 – Airfoillift, A = 6, R = 6 • 10^6 for smooth and rough surfaces
Рис. 19 – Подъемная сила крыла, A = 6, R = 6 • 10^6для гладкой и шероховатойповерхностикрыла
Slika 19 – Uzgon aeroprofila, A=6, R = 6 • 10^6 za glatke i hrapave površine

Figure 19 shows an C_L/α diagram of the airfoil observed under the same conditions, but with a different state of skin. It is clear that, with increasing roughness of the skin, the maximum value of the lift coefficient reduces together with a slight decrease of the lift gradient. It is noticeable that in this case airfoils behave similary after the decline of lift.

In real conditions, roughness is caused by aircraft production technologies and as such can be controlled and avoided on desired surfaces. During flight, there is damage to aerodynamic surfaces (to a lesser extent due to sand or insects and to a a greater extentdue to impacts of birds, which can lead to significant changes in the airfoil geometry).

A special case is the appearance of ice on leading edges, as a result of specific meteorological conditions of flight. Figure 20 shows the results of flow past the NACA 2212 airfoil, at $Re=4(10)^4$, with and without the effect of ice (Kostić, 2010).

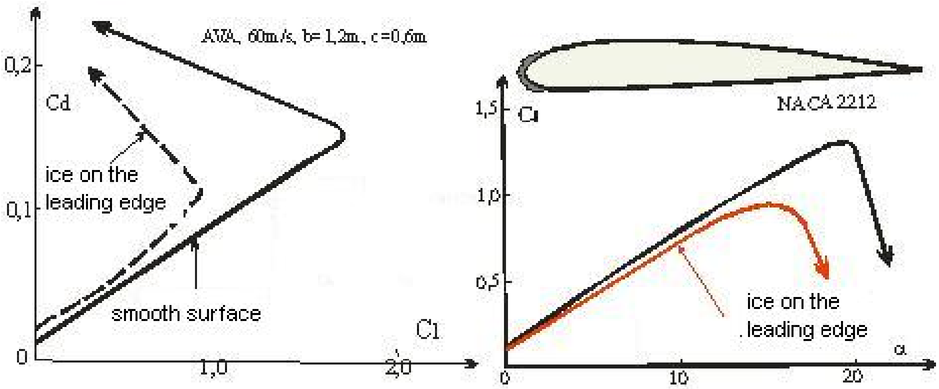

Figure 20 – C_L, C_D with and without simulation of ice on the leading edge of the NACA 2212 airfoil
Рис. 20 – C_L,C_D *с и без симуляции льда на передней кромке крыла NACA 2212*
Slika 20 – C_L, C_D sa i bez simulacije leda na napadnoj ivici za aeroprofil NACA 2212

Ice on the leading edge of the airfoil significantly reduces the value C_{Lmax} from 1.3 to 1.0; it increases the coefficient of resistance due to the increased turbulence of the boundary layer and increases the frictional drag.

In addition to the changes of the final values of the C_L and C_D, there are changes of their functions as well. TheC_D/C_L^2 ratio is affected, causing directly a change in the position of the aerodynamic center forward, which in flight requires an additional deflection of the rudder height, and thus a change of the angle of attack, which further complicates the problem of the spread of ice-affected areas.

The aerodynamic characteristics of the airfoil after stalling

Reaching the maximum lift with a further increase in the angle of attack leads to a faster or slower lift decline (depending on the observed flow past airfoils and its conditions). When the pitch-stall, or when a propeller pitch is increased, and also when there is a need for a reversible propeller pitch, the angle of attack increases.

In Figure 21, the behavior of the airfoil for given conditions of $\alpha=0^o$ up to $\alpha=180^o$ is shown (Critzos, 1985).

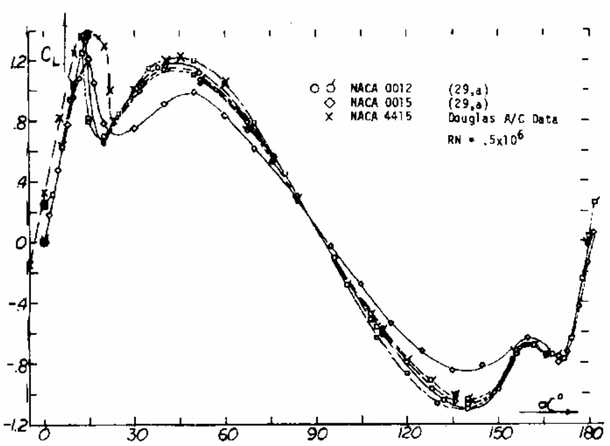

Figure 21 – Variations of the lift coefficient for α = 0°-180°
Рис. 21 – Вариации значений коэффициента подъемной силы при α=0°-180°
Slika 21 – Varijacije koeficijenta uzgona za α=0°-180°

The value of the airfoil lift coefficient is similar, but it can be seen that:

- After separation, the resultant force is approximately perpendicular to the chord;

- Lift force reaches the second maximum at $\alpha \approx 45^{o}$ ($C_D \approx 1.0$) so that the normal force is $C_N \approx \sqrt{2} = 1.43$.

- When $\alpha = 90^{o}$, $C_L \approx 0$ and $C_D \approx 1.8$, which is close to the value of the drag for a flat plate of the same angle of attack ($C_D \approx 1.95$);

- For the value of the angle of attack between 90° and 180°, it is characteristic that the sharp trailing edge has become a leading one, and the rounded leading edge has become a trailing edge, which is characterized by increased lift and reduced drag, but with different values and similar behavior.

Influence of the dynamics of the stall

In the previous analyzes of a stall, we started from the assumption that the change of the angle of attackis is gradual, so that we have considered stationary flow. But in real conditions of exploitation, changes of the angle of attack do not correspond to this assumption, especially if working conditions of helicopter rotors are taken into account, or parts of wing machinery during sudden maneuvers.

Figure 22 illustrates the changes in the lift coefficientat gradual and sudden changes in the angle of attack (Kostić, 2010).

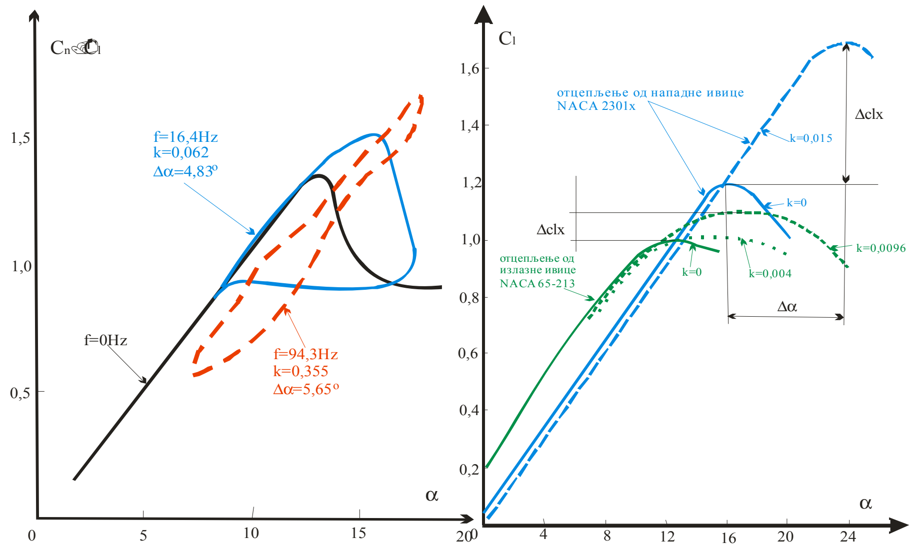

Figure 22 – Dynamic effects of changes in CL-α(t)
Рис. 22 – Динамические эффекты изменений CL-α(t)
Slika 22 – Dinamički efekat promena CL-α(t)

It is noticeable that a sudden increase in the angle of attack leads to a short-term lift increase. Keeping the angle of attack leads to a uniform flow past the airfoil, which leads to a stall.

A sudden increase in the angle of attack followed by return to its initial value shows that the value of the lift coefficient reduces compared to the stationary change of the angle of attack.

The diagram CL-α depends on the mode of airfoil entry into a stall. The cases of separation characteristic for the trailing edge have a more rounded shape of the curve than separation cases that occur at the leading edge.

The reduced frequency of changes of the angle of attack is $k=c\omega/V$, *where* c is the chord line, ω is frequency of changes of the angle of attack, and V represents velocity.

This equation is valid for non-compressible flow. For compressible flow, it is written as: $k=c\omega/V_0(1-M)^{1/2}$.

Conclusion

The selection of an aerodynamic shape of an object in an air stream is a complex task. It is in relation to the conditions and purpose of flow past an objectas the starting factors. One of the limiting factors in exploitation is turbulence.

The analysis of experimental aerodynamic characteristics of different types of airfoils at different flow conditions categorized according to the Reynolds number has led us to a physical interpretation of the formation of laminar and turbulent flow separation.

We can conclude that the behavior of the airfoil at critical angles of attack:

- directly depends on the type of the airfoil and the local characteristics for the defined conditions of the flow;
- depends on the dynamics of the angle of attack increment at its critical values.

Based on the systematically presented results, it is possible to optimize the airfoil selection and reduce the number of iterations in the process, thus reducing the time and cost of design.

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АЭРОДИНАМИЧЕСКИЕ ХАРАКТЕРИСТИКИ КРЫЛА
ПРИ КРИТИЧЕСКОМ УГЛЕ АТАКИ

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Резюме:

При разработке летательных аппаратов неследует пренебрегать фактором возникновения чрезвычайных ситуаций, а также условиями близкими критическим, так как при критическом угле атаки, обычный полет может перейти в аварийный режим.

В данной работе приведены важные факторы, влияющие на состояние крыла в течение полета при критическом угле атаки. На основании доступных испытательных результатов и расчетов, произведен анализ поведения крыла в зависимости от условий обтекания (в соответствии с классификацией чисел Маха и Рейнольдса), формы крыла, динамики угла атаки. В работе также описано обтекание крыла при критическом увеличении угла атаки, и влияние неровностей на поверхности крыла в подобных условиях.

В данной работе также представлены физические параметры критического режима полета, в т.ч. снижения подъемной силы и сваливания. Подробно описан процесс обтекания крыла с отрывом потока и выполнена классификация типов профелей с учетом срыва струи и поведения крыла в критическом режиме полета.

Цель работы заключается в выявлении наиболее значимых характеристик обтекания крыла при критическом угле атаки и анализе, проведенного на основах современной аэродинамики, в результате которых предлагается практическая рекомендация для выбора аэродинамического профиля. Результаты данной работы могут представлять интерес как для летчиков и инженеров, так и для образовательных и исследовательских учреждений.

Ключевые слова: *аэродинамика, форма и вид крыла, динамика флюидов, производительность крыла, критический угол атаки.*

AERODINAMIČKE KARAKTERISTIKE AEROPROFILA PRI KRITIČNIM NAPADNIM UGLOVIMA

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OBLAST: mašinstvo
VRSTA ČLANKA: pregledni članak
JEZIK ČLANKA: engleski

Sažetak:

Prilikom konstrukcije vazduhoplova ne sme se zanemariti ponašanje letelice u ekstremnim, odnosno blisko ekstremnim uslovima leta, kakav je let pri kritičnim napadnim uglovima, gde se normalan let može lako preobratiti u prevučen let.

U ovom radu naglašeni su bitni činioci koji utiču na ponašanje aeroprofila u letu pri kritičnim napadnim uglovima. Na osnovu dostupnih eksperimentalnih rezultata i proračuna izvršena je analiza ponašanja aeroprofila u zavisnosti od uslova strujanja (kategorisanih prema Mahovom i Rejnoldsovom broju), oblika aeroprofila, dinamike priraštaja napadnog ugla, opstrujavanja aeroprofila sa povećanjem napadnog ugla nakon dostizanja kritične vrednosti, kao i uticaja površinskih neravnina aeroprofila pri kritičnim napadnim uglovima. Prikazano je i fizičko tumačenje pada uzgona i pojave prevučenog leta. Detaljno je opisan nastanak otcepljenja strujanja oko aeroprofila i izvršena kategorizacija aeroprofila prema tipu otcepljenja i njegovom ponašanju pri kritičnim napadnim uglovima opstrujavanja.

Cilj ovog rada jeste da na savremenim osnovama aerodinamike prikaže i obrazloži problematiku i najznačajnije osobenosti opstrujavanja aeroprofila pri kritičnim napadnim uglovima, da dâ praktične preporuke prilikom izbora aeroprofila, a može biti koristan i pilotima, inženjerima i istraživačima.

Ključne reči: *aerodinamika, performanse aeroprofila, dinamika fluida, oblik aeroprofila, kritični napadni ugao.*

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CRITICAL INFRASTRUCTURES: THREATS, VULNERABILITIES AND PROTECTION

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Abstract:

This paper presents six critical infrastructure sectors: electric power systems, energy sources and supply, manufacturing, transport and storage of hazardous substances, traffic and transportation, information-telecommunication infrastructure, and supply with basic viands. The sources of adverse unwanted events due to accidents, technical faults, natural disasters, and human error are presented. Prediction and prevention of these events are explained in details.

Key words: *transportation, protection, vulnerabilities, threat, critical infrastructure, hazards.*

Introduction

Critical infrastructures are important infrastructures the destruction or incapacity of which can have tremendous consequences for national security, economy, environment and people. Critical infrastructure relates to assets, physical facilities, systems, communication networks, processes and supply chains which, if destroyed or degraded, would significantly affect the well-being of the nation. Disruption of critical infrastructure can result in catastrophic loss of life, adverse economic effects, etc.

Critical infrastructure protection involves programs and activities implemented by government, regulatory bodies, research institutions, users and owners, in order to reduce vulnerability in case of an unwanted event. It also includes crisis management in order to strengthen resilience of critical infrastructure (Lewis, 2006). The European Union (EU) (2006) has adopted the action plan for the protection based on the prevention of incidents which may disrupt critical infrastructure security. The plan relates to detection and response to security breaches, recovery from accidents, and international cooperation. According to this plan, critical infrastructure consists of activities, networks, services, material goods and information technology that, if destructed, can have significant impact on health, safety and economic prosperity of the citizens and/or the economy of the member-states. Also, national critical infrastructures of member-states are defined as systems, networks and facilities of national importance whose disruption may have serious impacts to national security, health, property, environment, security, economic stability and governments (Protić, 2012, pp.82-101). In Great Britain, Sweden, Netherlands and Switzerland, the most common critical infrastructure is telecommunications. In Germany, one of the most important critical infrastructure sectors is also communication infrastructure, (O`Neil, Dempsey, 2000, p.12), Canada and Australia also included mass media. In the United States of America (US) critical infrastructure sectors are agriculture, food, water, public health, emergency services, government, defense industrial base, information and telecommunications, energy, transportation, banking and finance, chemical industry, postal and shipping (Kljajić et al., 2010, pp.75-78). Considering that disasters and adverse unwanted events most often occur locally, national strategies ensure that the first response to emergencies is local. On the other hand, federal authorities have responsibilities to manage emergencies at the national and global level (Službeni glasnik, 86/2011). Also, their jurisdictions are laws and regulations in this field, as well as strategy for increasing resilience of critical infrastructures. In 2012, Gospić et al. summarized critical infrastructures in information and communications, electric power, transportation, oil & gas, banking and finance, water & emergency services, and government (Gospić et al., 2012, pp.51-59). Moreover, the authors refer to the standards in risk management which are also the scope of this work.

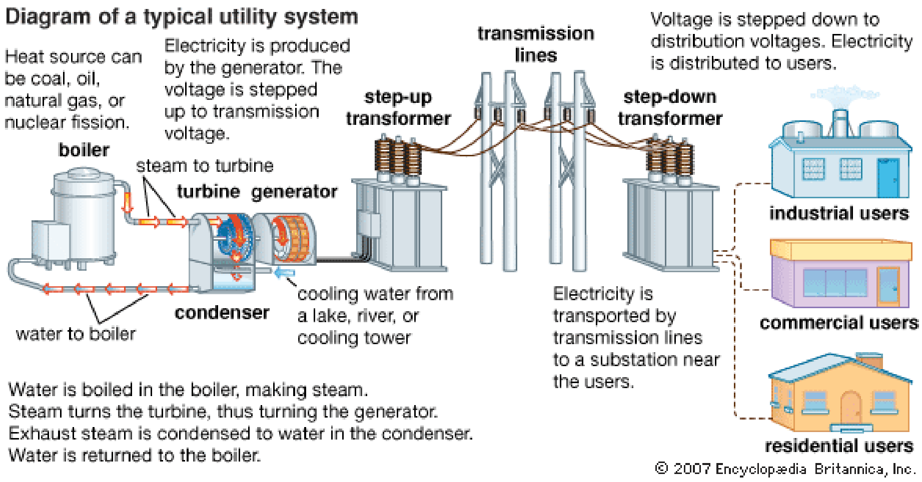
In accordance with the literature rewiev and the good practice, six critical infrastructure sectors are presented here, respectively: (1) electric power systems, (2) energy sources and supply, (3) manufacturing, transport and storage of hazardous substances, (4) traffic and transportation, (5) information-telecommunications infrastructure, and (6) supply with basic viands (NIPP, 2013). Threats, vulnerabilities and protection of these infrastructure sectors are shown in the following text, respectively. The last chapter concludes the paper.

Electric power systems

Electric power systems belong to the world's most complex man-made systems. Power generation, long-distance transmission lines and local distribution systems must all work together to deliver electricity to a range of users (https://mitei.mit.edu/). Electrical power outages significantly affect society and economy, causing cascading effects. Protecting this critical infrastructure implies the preservation of its basic functions in a way that is consistent with appropriate risk assessments, which are carried out in several phases. First, the sources of risks are examined. They may be technical or mechanical, natural disasters, human errors, and the like. Then, the following impacts of accident are estimated: 1) rapidity (constant, slow, fast speed), 2) duration (intermittent, continuous), 3) spread effects (local, national, global), 4) frequency (event happens frequently, sometimes, again), 5) reliability (deterministic, heuristic, unknown), etc. The protection is carried out at power sources, generators, transmission lines, distribution systems, information and communication systems, etc. Protective equipment is used, as well as mechanisms for switching electrical circuits, protective relays, protective chambers and SCADA (Supervisory Control and Data Acquisition) systems, for generator monitoring, whereas consoles which monitor production no longer have to be in the vicinity of the manufacturing plant (Inductive automation, 2016). The problem that arises is a cyber-attack.

Production and distribution of electrical energy

Electrical energy is generated by production plants where the primary source of energy is converted into electrical energy. Conventional power plants can be hydro, thermal and nuclear power plants (Rajković, Kukulj, 2011). Hydroelectric energy is converted by hydraulic turbine coupled with a generator. In a thermal power plant, fuel is burned in steam boilers in which high-pressure steam is produced. A steam turbine converts steam into mechanical energy. A nuclear power plant consists of a nuclear reactor which generates heat by nuclear fission of uranium. Heat passes to liquid carbon dioxide, water or sodium. Processes that follow are similar to those in thermal power plants. Figure 1 gives a diagram of a typical system for the generation, transmission and distribution of electrical energy from power plants to industrial, commercial and residential users, i.e. consumers (www.kids.eb.com).



Picture 1 – Production and distribution of electrical energy
Рис. 1 – Производство и распределение электрической энергии
Slika 1 – Proizvodnja i distribucija električne energije

Electric power networks consist of a distribution system that includes low-, medium-, and high-voltage networks, substations, information and telecommunication systems, and other energy facilities for maintenance and management of the network and equipment.

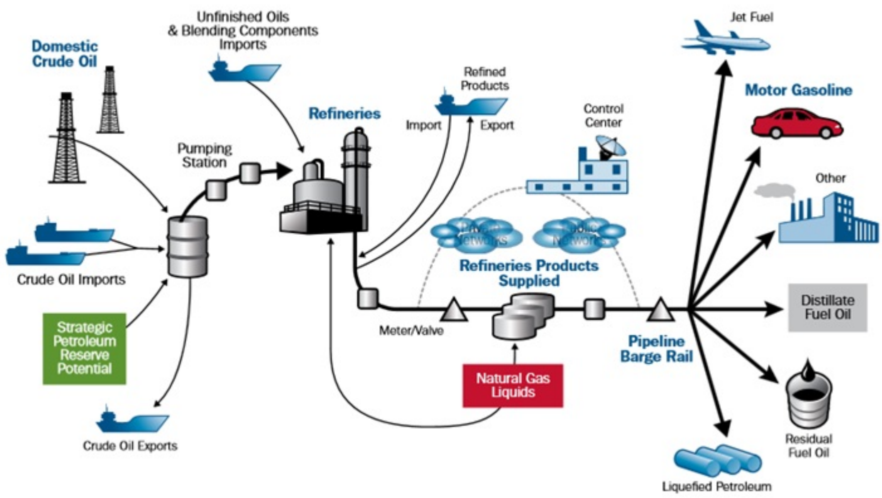
Safety in the production and distribution of electrical energy is based on the resilient system and surveillance, guard, duplication of the most important equipment, because the outage of any part of the system may cause long-term losses and consequences on health and environment. Losses can be (1) related to the IT sector, (2) material (3) destruction of equipment, (4) various damage in urban areas, etc.

Renewable energy

Hydropower, wind, solar energy, biomass energy and geothermal energy are all renewable energy sources (Jovanović, 2013). In contrast to energy sources such as coal, oil, or gas that pollute environment and cause the greenhouse effect, renewable energy sources are inexhaustible and do not pollute the environment. Protection of renewable sources is identical to the principles of the protection of other energy power systems (physical security, monitoring, SCADA). Special attention is paid to possible damage of pipelines for hot water in urban areas.

Energy sources and supply

Energetic stability is a subject of growing global concern because a large number of countries do not have their own sources to ensure energy independence (Kolev, 2013, pp.31). Instead, they often rely on energy sources located in other countries, which are often away and sometimes unstable. Today, considering complicated modern energy security challenges, decision-makers of every state should first learn scientific approaches to the new field of protection in energy policies in order to be able to deeply understand the national-level cooperation on economic, political, infrastructure and military aspects. In this regard, energy planners are responsible for critical energy infrastructures regarding the protection of energy facilities and infrastructures in state territories (see Figure 2), involving measures oriented to prevent damage and restore safe and reliable energy supply sources under the best conditions. (Hazard strateji enstitutsu, 2014).



Picture 2 – Energy sources and supply chains
Рис. 2 – Энергоисточники и сети истемы снабжения
Slika 2 – Izvori energije i lanci snabdevanja

Measures and actions taken in order to achieve a reliable and safe energy supply, qualitative distribution of electricity, environment projects, cooperation with other countries, market development, etc. represent the energy policy of any state and are preventive measures for protection. Three paragraphs that follow describe the protection of gas supply, oil and petroleum product supply and supply of solid fuels, respectively.

Gas supply

From an economic and ecological point of view - gas is the most acceptable energy source. It is produced by dry distillation of coal, by-products of agricultural waste or by gaseous fuel from other gases by purification, or blending. Gas supply is a chain that consists of natural or synthetic gas production, pipelines and distribution network. In this chain, a big role is also given to dealers who organize the sale of gas through the distribution network to customers. Gas supply does not include the extraction of natural gas, coke ovens operation, manufacturing petroleum derivatives and technical fuel, and distribution of gaseous fuels through transport pipelines. Customers of natural gas, the facilities of which are connected to the distribution system and customers who buy small quantities of gas are entitled to public supply, and the rest of the customers buy gas from the licensed supplier (Agencija za energetiku RS, 2015).

To connect to a pipeline, one should have a house connector, a control/measurement set, gas installation and a consumption counter. Communal inspectorate, sanitary inspectorate and fire police are responsible for safety of gas distribution and gas supply. The very fact that these inspectorates exist clearly indicates the system with a high risk. The prevention measures needed for this system are the following: employees have to be familiar (or educated) with technical regulations, connectors and distribution network, they need to know protective measures against fire, first aid, etc.

Oil and petroleum products supply

In accordance with the objectives of energy policy, it is necessity to increase supply of oil and petroleum products and thus facilitate development of a competitive market, which encourage the development of economy and at the same time retain economic control in the transport via pipelines, and transport of derivatives through product pipelines. The overall structure of petroleum products is dominated by motor fuels (gasoline, diesel, jet fuel, liquid petroleum gas), fuel oil, etc. (Komisija za zaštitu konkurencije RS, 2012).

Facilities for oil and petroleum derivatives must be constructed to follow technical rules for manufacturing space, equipment, devices, storage, and sale. Protection is performed as follows: the fuel pump must have indoor and outdoor space, the surface must be built on solid materials (concrete, stone, asphalt), the space should be illuminated, and the pumping machine must be marked clearly and connected to the tanks for dispensing. Facilities for wholesale trade of oil must be fenced having tanks whose volume depends on the derivative.

Storage of oil, petroleum products and biofuels are in a direct relation with trade so economic entities engaged in this activity must have appropriate permissions to trade (Službeni glasnik RS, 57/2011). However, since the requirements for obtaining such licenses are rigorous in terms of security measures, this is the first line of defense against accidents, errors or malicious attacks on supply and storage.

Solid fuels supply

Solid fuels are used for electricity generation in thermal power plants, in agriculture, industry, heating plants, and in households as firewood (Marković, 2011). The combustion of solid fuels has one of the largest impacts on health and the environment. Solid fuels are a complex combination of chemical and biological substances so their combusting result in the emission of sulfur oxides, carbon monoxide, nitrogen oxide, flying particles of ashes, organic materials, gases, microelements, and halogens (fluorine and chlorine).

Large-scale fires are rare in solid fuels supply chain. Nevertheless, industry has to apply the prevention measures by training personal for fire protection, the first aid, handling combustible materials, maintenance of storages, and similar.

Manufacturing, transport and storage of hazardous substances

Critical infrastructure that consists of manufacturing, transportation and storage of dangerous, hazardous materials, is one of critical infrastructures that influence economy and relate to other critical infrastructures. One of the reasons is that hazardous materials, during manufacturing, transportation, storage or handling, can be extremely dangerous to the health and environment. On the other hand, hazardous substances are important and used on a daily basis in households, agriculture and industry. Depending on their chemical characteristics, their aggregate state, and a degree of hazard, dangerous substances are classified in 13 classes as follows: (1) Class 1 – explosives and objects with explosive materials, (2) Class 2 - gases, (3) Class 3 – flammable liquids, (4) Class 4.1 – flammable solids, self-reactive substances and de-sensitivity explosives, (5) Class 4.2 – substances liable to spontaneous combustion, (6) Class 4.3 – substances that emit flammable gases in contact with water, (7) Class 5.1 – oxidizing materials, (8) Class 5.2 – organic peroxides, (9) Class 6.1 – Toxic materials, (10) Class 6.2 – infectious substances, (11) Class 7 – radioactive substances, (12) Class 8 - corrosive substances and (13) Class 9 – other dangerous substances (Zakon o prevozu opasnih materija, 2002). Chemicals are classified as elementary, special, agricultural, pharmaceutical and those for consumer usage (Službeni glasnik RS, 36/2009, 88/2010 and 92/2011).

Products of chemical industry are used as fertilizers, chlorine for water treatment, polymers for oil derivatives manufacturing, product for households, industry and many more. Considering the diversity of industry, it is very difficult to determine the profile of protection in general. Instead, risks are assessed for each production-consumption chain, due to the variety in manufacturing technology, design of products and relevant manufacturing processes. Vulnerabilities are related to: 1) terrorist attacks and the release of dangerous chemicals that could potentially endanger human lives, 2) chemical weapons or products that can be used as weapons, and 3) psychological effects of the consequences of accidents on the population. Threats can be natural disasters, caused by human factors, technical threats or malfunctions, disruption of electricity, and similar. Natural disasters can be earthquakes, eruptions, windstorms and hurricanes. Human accidental or intentional errors can be terrorism, cyber attacks, explosions, bombing, as well as traffic accidents, breakdowns, etc. Law, rules and standards regulate safety of manufacturing, usage and storage of hazardous materials in order to reduce the probability of accidents. Attacks on critical infrastructure, technical errors and malfunctions result in large pollution so it is extremely important to ensure all processes from manufacturing to consumption. Numerous raw materials, by-products and final products are carriers of risks in the manufacturing and handling hazardous substances. Accidents concerned with them cannot be predicted. For that reason, the necessity is education in areas related to a specific vulnerable system, hazardous substances, policies, standards and regulations. Additional education of personnel should be performed periodically during their professional engagement.

Production of hazardous substances

A large number of manufacturing plants which use various raw materials and products based on highly toxic chemicals are a serious threat to a broad territory, with unforeseeable consequences for people, environment and the economy, if an accident happens (Gaćeša, 2012, pp.312-315). For these reasons, production of hazardous substances has to be ensured from any occurrence of incidents. That is why manufacturing processes are separated one from another. (To prevent a possible cascade effect that could affect other parts of the industry process.) For this purpose, a control system for monitoring and alerting can be very useful and important. Also, a major role in a crisis that arises from an unwanted event such as malfunction, technical errors, human error, or similar, is played by staff trained to react quickly to accidents (calling emergency services, fire fighting, first aid, etc). Panic in working with hazardous substances must be reduced to a minimum.

Transport of hazardous substances

One of the risks of handling hazardous substances is moving them from one place to another. Hazardous substances are transferred by roads, railways, waterways and through the air, in accordance with internationally agreed rules, recommendations and predefined procedures for carrying out safe transport (Služben glasnik SRJ, 15/1995, 28/1996 and 37/2002). Senders, carriers and recipients participate in the transport of hazardous materials and follow several steps: senders determine whether the substances are classified in accordance with standards and give information about them to carriers. Carriers must have permission to transport goods. In addition, they are obliged to use appropriate packaging for the transport and to ensure that empty packages are cleaned and properly marked. Carriers note that hazardous materials fulfill legislations, provide transport documents, visually inspect and check that everything is according to standard, note if all permits are valid, verifiy that a vehicle is not overloaded, etc. Recipients shall not postpone the receipt of goods without any particular reason and must confirm receipt of hazardous substances. They examine goods and documentation and provide unloading only if there were not failures in transport. Finally, they clean and decontaminate vehicles or containers. If there are changes in goods, the recipient can refuse reception.

Storage of hazardous substances

Warehousing of hazardous substances ensures maximum protection and minimum risks of serious injuries and damage to the environment (Službeni glasnik RS, 92/2010). Storage of hazardous materials is performed by qualified personnel, responsible and licensed for handling dangerous substances. The warehouse must be built in accordance with regulations, standards, technical requirements, government planning, and construction of warehouses. Access to the warehouse must be protected from accidents. The space for storage must meet requirements for humidity, temperature, air pressure and lighting. The warehouse must be cleaned, while explosive and flammable materials must be arranged by type and kept at distance. Empty containers must be stacked according to the type and packed to be sealed with the proper lids, and resistant to the chemicals inside.

Traffic and transportation

Economy and quality of life depend on traffic and transportation systems that function well. Traffic and transportation connect people to jobs, family, medical care, education, and goods needed for everyday life. As with other major critical infrastructures such as water or electricity supply, the importance of traffic and transportation systems become apparent only when problems arise (Transportation Research Board, 2005). Maintenance and protection of this critical infrastructure is one of the key prerequisites for achieving sustainable economic and social development.

Although the terms traffic and transportation are often used interchangeably, in essence they do not have the same meaning. Transportation is a commercial service activity were goods, passengers or energy are moved, conveyed or carried from one place to another. On the other hand, traffic is organized passage of people and vehicles along routes of transportation, which is the result of applied technology and transportation needs. It is a public service, which is tasked to meet the needs of society, i.e. traffic is broader term than transportation.

Traffic and transportation belong to critical infrastructure because of the function of connecting points/destinations, in order to transport people, goods, products, semi-products and derivatives, in a variety of transportation means. Roads, ports, railways, airports, power systems and telecommunications in traffic and transport are most vulnerable to physical damage. A significant part of this infrastructure is an information system for accessing and processing information, maintaining communication during transportation, accessing databases, positioning and other services vulnerable to cyber attacks.

Traffic and transportation networks

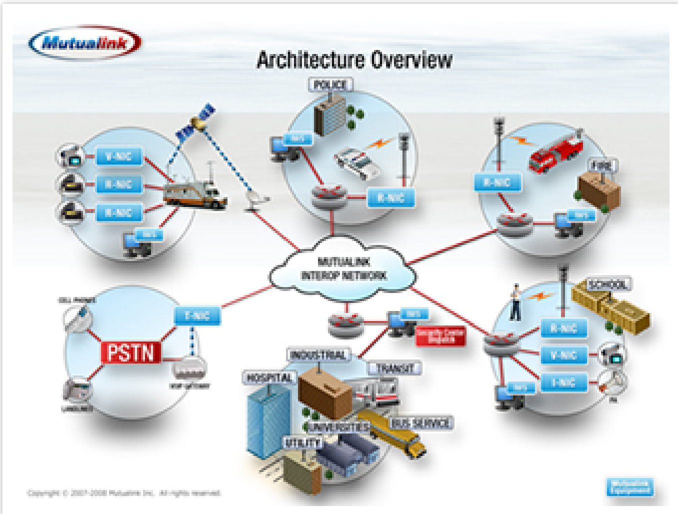
Traffic covers provision of transportation services of passengers and freight via roads and railways, waterways and air, as well as services on terminals, parking lots, covering storage and handling cargo. Transport refers to the land infrastructure (highways, bridges, tunnels, and viaducts), aviation (planes and other aircraft, air traffic control, airports, heliports, runaways), waterway infrastructure (coast, ports, waterways, intermodal terminals) and rail transport (highways, secondary active rails, freight wagons, locomotives). In addition, postal transport is one of the essential parts of the transport system.

Bridges, viaducts and tunnels are assessed as high-risk infrastructure for transport. The protection is performed by building flexible bridges with embedded systems for flood and fire protection, help-lines, etc. Modern bridges are equipped with sensors for monitoring the structure to avoid a crisis if the sensors detect the vibrations of the cables, for example. Detectors can be accelerometers, strain gauges, anemometers, temperature sensors, etc. The same principles of protection apply to viaducts since they are bridges over the ground. Tunnel protection is mainly carried out in the process of planning, in accordance with standards for constructions and materials.

Airport operations rely on complex, bounded and stacked infrastructures. An airport is a part of aviation that includes aircraft, air-traffic control, commercial airports, additional airports, heliports, and landing strips. Aviation also includes civil and joint use military airports, heliports, short takeoff and landing ports and seaplane bases (Homeland Security). Four types of events are closely associated with the airport infrastructure: (1) a planned event, (2) an incident, (3) a disaster that causes a lot of damage, but can be managed with an appropriate assistance and (4) a large-scale disaster (catastrophe) that completely disables communities or regions in which it has appeared. Catastrophes can be caused by natural disasters (gale-force winds, floods, earthquakes, landslides, eruptions, wild fires, ice storms), accidents (falls, industrial accidents, infrastructure failures, mechanical failures, human errors), pandemics (SARS, biological weapons), unrests (riots, strikes, demonstrations, boycotts, sabotage), terrorism (explosives, hostages, kidnapping, cyber-crime), and the like. What is most important in protecting airports is to ensure continuity of operations in urgent situations (prevention, preparedness, mitigation, response to crisis, recovery from crisis and reconstruction). A quick reaction is the task of response teams; however, the structure of the airport, organization, management policies and defense must ensure normal functioning in an emergency as well.

Information and telecommunication infrastructure

Communications, energy, transportation, water supply and other critical infrastructures largely depend on computer networks whose functions of generation, processing, storage and data transmission are very vulnerable to malicious attacks that can extremely destabilize the economy, jeopardize national security and disrupt the quality of daily life. Generating, processing, and exchanging information are now fast and efficient, which significantly reflects modern business and life in general. At the same time, all the benefits provided by development and implementation of new technologies have become a source of potential attacks on sensitive information that can be available to unauthorized users, modified, or destroyed. Figure 3 presents the architecture overview of the interoperable communications platform that links together police, fire, hospitals, schools, mails, and other community assets (www.mutualink.net, 2009). This platform is one of various tools for improving community safety and readiness.



Picture 3 – Mutualink platform
Рис. 3 – Мутуалинк платформа
Slika 3 – Mutualink platforma

The Mutualink is a comunity wide inter-operable multimedia platform which links together two-way radios, telephones, and public address systems is such a way that video and data files can be shared among parties on a real-time incident basis, which enhances preparedness and effectiveness in an emergency.

Telecommunications network

A telecommunications network is a structure of computing telecommunication resources for communication and information between distant locations. Telecommunications networks include terminals (for accessing the network), computers (that process information and are interconnected by the network), links (that form a channel through which information is transmitted from a sending device to a receiving device), telecommunications equipment (that facilitates the transmission of information), and telecommunications software (that controls message transmission over the network) (http://www.umsl.edu/).

Two principal types of telecommunications networks can be distinguished from the point of view of their geographical scope: Local Area Network (LAN) and Wide Area Network (WAN), each of them containing active equipment (switches, routers, PBX equipment, wireless communications, optical converters), and passive equipment (optical and copper cables, antennas, sockets). Telecommunications networks can be public, mobile, cable, hybrid, optical access networks, low voltage networks, etc (Vujić, Dukić, 2015). The first one is used between stationary terminal points. In a mobile network, terminal points are not at specific locations and the terminal-points connections are carried out via the radio. Cable networks are primarily designed for TV signals transmission to the terrain where the classic reception is not possible (a large number of users receive the same content). In the hybrid network, the access network is realized with coaxial cables, while fiber optic cables are used to connect the central hub and peripheral hubs. The optical network provides a broad access solution with transmission based on multiplexing. A low-voltage power network can be used as a telecommunications network in suburbs or villages, with approximately equal distribution of housing facilities throughout the territory, where substations must be close to each other. A low-voltage network is a poor transmission medium, having low bandwidth and high interference.

Telecommunications networks connect other critical infrastructures, so that any potential vulnerability of these networks is a threat to telecommunication networks and vice versa. Vulnerabilities occur at devices, network infrastructures, data content, etc. so combating threats requires a cooperation between manufacturers, operators, providers, suppliers, users and the state, which must be focused on the prevention and awareness of threats.

Information and communication system

The information and communication system consists of personnel, hardware, software, cable connections, wireless connections, power supply, and equipment. Each of the assets plays a role in maintaining transmission between users or between other systems. For that reason, processing and distribution of information have to be carried out in real time, thus meeting the needs of users, business and public services, whose activities are related to the online communication.

The structure of the information and communication system indicates the vulnerability of a large number of elements that can be classified into: physical threats (architecture, hardware, power supply) and cyber threats (information processing, decision-support systems, and services). The information and communication system can be impacted by natural disasters (physical destruction), industrial accidents (construction collapse, fire), product or service failures (communication failure, data centre failure), public relations (unwelcome media attention, adverse publicity of media), business and management (hostile takeover, sudden strike, competitor launches new product), etc. It is impossible to protect information and communication systems from all threats. However, prevention of some accidents (before they happen) and response to them (after they occur) can be done. There are four steps to ensure business continuum: (1) planning (getting business in the best position to react to, and recover from, an emergency), (2) incident response (processes put in place to ensure that business reacts properly and orderly to an incident as it occurs), (3) accident management (coordination of responses to an incident that threatens to harm, or has harmed, people, structures, ability to operate valuables and reputation), (4) business continuity (restore system to normal functions) (Holman, Houser, 2011).

Absolute protection of information and communication systems is impossible to achieve, but it is possible to achieve a high level of security within a network, operating systems, applications, databases and procedures. For information and communication systems, security can be achieved by the CIA Triad (Confidentiality, Integrity, and Availability). Moreover, protection are authentication, accountability, access control, non-repudiation, intrusion-detection, Denial of Service, etc. (IBM, 2005). That provides access control, identity verification, encryption, confidentiality, etc.

Attacks to the information and communication infrastructure can be diverse: passive and active, internal (insider) or external, and similar. The most known attacks are (1) Denial of Service – the legitimate users are not allowed to use the network because of overloaded network services. This attack paralyzes the functions of the server, or a web site. The attack reduces bandwidth and damages information about configuration. The protection can be carried out by turning off some network services, back upping, etc. (2) Phishing is a form of fraud in which the attacker tries to learn information such as log in credential, or accounting information, by masquering as a reputable entity or person in e-mail, instant message, and other communication channels. A gateway e-mail filter can trap many targeted phishing e-mails. A web security gateway can also provide another security layer by preventing users from reaching the target of malicious link. (3) Botnet is a collection of compromised computers often referred as zombies infected with malware that allows an attacker to control them. Botnet owners are able to control the machines in their botnet by means of covert channels such as Internet Relay Chat, issuing commands to perform malicious activities such as sending spam mail, and information theft. (4) Spam is an electronic version of junk mail. An unsolicited e-mail involves sending unwanted messages to a large number of recipients. To-do measures against spam are installing spam filtering/blockage software, deleting e-mails suspected as spam, reading e-mails in plain text, keep software and security patches up-to-date, etc. (5) Sniffing and spoofing refer to listening to a conversation. Sniffer is an application that can capture network packets using a sniffer. Once the packet is captured, the contents of packets can be analyzed. Sniffers are used by hackers to capture sensitive information such as passwords, account information, etc. The attacker can follow the path until he finds the switch to which he is connected. From there, the attacker can enable a monitor port as the port to which he is connected. Switch security is the first line of network security from internal hacking. Switch security is the path attackers must go through to get to the rest of the network (Tetz, 2015). Spoofing refers to actively introducing network traffic pretending to be someone else. It is typically used in a scenario where one generates network packets that say they originated by computer A while they are really originated by computer B. (6) Malicious software (malwer) is any software that gives partial to full control of one's computer to do whatever malware creator wants. Malwares are categorized as viruses, worms, trojans, and backdoors. Adware and spyware seek to embed themselves to watch what the user does, and act upon that data. Root kits seek to give full access of one's machine to the attacker to do what they want (http://www.seas.ucla.edu).

Supply with basic viands

Supply with basic viands has critical dependencies with transportation systems, energy sector, water systems, chemical and dams. This critical infrastructure comprises manufacturing, processing and delivery systems,which consist of farms, restaurants, warehouses, etc. Critical infrastructure of basic viands supply consists of two sub-structures. One supplies people with water and the other one supplies them with food. These two infrastructures are described in the chapters that follow.

Water supply

Water supply and quality of drinking water are indicators of population's health, thus confirming their important role in daily life. Changes in water supply cause discomfort and anxiety in people, reduce hygiene and affect life and economy in general. Consequently, water supply is a critical infrastructure. The sector of water supply is sensitive to a number of possible attacks including contaminations, physical attacks, or release of toxic gases. The results of attacks are sick or dead people, and disabled services such as fire fighting, working of hospitals, storage of meat products, etc.

Water supply is a complex system that consists of hydraulic structures, i.e. (1) wells (water supply systems that have water reservoir and water distribution and fountains), (2) systems for raw water transportation, (3) water treatment plants, and (4) distribution networks consisting of tunnels for primary transport, water supply networks, pumping stations and reservoirs.

The protection is carried out through prevention, control and maintenance. Water used for public supply must be safe to drink, according to the predescribed standards, recommendations and directives, which are mandatory in the country. Water quality is determined by inspection of physical, chemical and microbiological parameters. During each inspection, data is taken from (1) sources (2) reservoirs, and (3) distribution networks. Principles of risk assessment are monitoring and reporting on water pollution indicators. Pollution is a chemical, physical or biological change in water that has a negative impact on people and/or environment. Water pollutants can be concentrated facilities such as urban areas, industrial facilities, landfills, or can be spread out such as land with pesticides and fertilizers, or dumps.

Food suply

Production, distribution, storage, and supply with food is one of the most critical infrastructures that depends on many other critical infrastructures, such as production and distribution of water, transportation, energy, chemicals' supply and others. Bases of this critical infrastructure are (1) acquisition of raw materials, cultivation of crops and livestock (2) manufacturing, processing and packaging of food, (3) storage, and (4) transportation and distribution of products.

The protection is implemented in the food supply chains for livestock and livestock food, in vegetable production chains (seeds, fertilizers), and in other parts of infrastructure for manufacturing, storage and distribution of food. The focus of food safety is to protect the food supply from chemical, biological, radiological and other contamination. Deliberated actions on the food supply chain are unpredictable but accidental contamination can be prevented or early detected to minimize the consequences of an accident.

Conclusion

Critical infrastructures have a significant role in national strategies of many countries, which increasingly intensifies efforts in protection of these vulnerable systems. Strategies for the protection of critical infrastructures have become strategies of sustainability of government, economic stability, prosperity, industry, public health and environment. In the last two decades, the most important critical infrastructures were electric power systems, transportation, water and food supply, agriculture, and vital industrial plants. In the modern world, information and telecommunications technology, mass media, banking and finance, and the environment have also become critical infrastructures.

Each state determines its own critical infrastructures in accordance with the requirements of its national policy. Unions, such as the EU, have certain criteria for the Union, while each state is free to estimate their critical infrastructures. Results from practice show that the most known critical infrastructures are electric power systems, energy supply, manufacturing, transport and storage of hazardous substances, traffic and transport, information and telecommunication infrastructure and the supply of basic viands, described in this paper.

Depending on the type of infrastructure, threats to critical infrastructures can be classified into two groups: physical threats, and cyber attacks. Pipelines, substations, warehouses, communications infrastructure and industrial plants are mostly exposed to physical threats. Cyber threats jeopardize systems for monitoring and control, databases, operating systems, software, automated production facilities, and the like.

Vulnerabilities of critical infrastructures are determined by their functions. Generators, distribution networks and information and telecommunication networks are vulnerabilities of electrical power systems. In energy sources and distribution networks, these are gas and oil pipelines, manufacturing and warehouses. In the production and treatment of hazardous substances, vulnerabilities are products as well as transportation and storage of substances. In traffic and transportation, the most vulnerable structures are airports, bridges and tunnels. Physical infrastructure is one of the two vulnerabilities in the information and telecommunication systems. The other one is related to the communications. Manufacturing, supply and storage of food and water are vulnerabilities of viands.

Protection of critical infrastructures has to be carried out for each infrastructure depending on its threats and vulnerabilities. It is necessary to protect all parts of the critical infrastructure considering various functions and physical infrastructure. It is essential that a risk is assessed and that all employees are well trained. Physical protection of systems is performed by fencing, guarding, blockades, or separation of production processes because of the domino effect. Protection against cyber attacks is important in infrastructure components which are controlled by computer networks, connected to the Internet, or based on automated production processes.

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КРИТИЧЕСКАЯ ИНФРАСТРУКТУРА: УГРОЗЫ, УЯЗВИМОСТЬ И ЗАЩИТА

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ОБЛАСТЬ: электроника, телекоммуникации, безопасность, транспорт
ТИП СТАТЬИ: обзорная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

В данной работе приведены шесть видов критической инфраструктуры: электроэнергетические системы, сети распределения и снабжения энергоносителей, производство, сбыт, складирование и хранение опасных материалов, первозка и транспорт, информационно-телекоммуникационные сети, снабжение продуктами питания.

В статье также представлены источники возникновения потенциальных аварий, чрезвычайных ситуаций, несчастных случаев, технических ошибок, опасных природных явлений и влияние человеческого фактора. Подробно описаны мероприятия по предотвращению и профилактике приведенных рисков.

Ключевые слова: *транспорт, защита, уязвимость, угроза, критическая инфраструктура, случай, риски.*

KRITIČNE INFRASTRUKTURE: PRETNJE, RANJIVOSTI I ZAŠTITA

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OBLAST: elektronika, telekomunikacije, bezbednost, saobraćaj
VRSTA ČLANKA: pregledni članak
JEZIK ČLANKA: engleski

Sažetak:

U radu je prikazano šest kritičnih infrastruktura: elektroenergetski sistemi, mreža distribucije i snabdevanje energentima, proizvodnja, promet i skladištenje opasnih materija, saobraćaj i transport; informaciono-telekomunikaciona infrastruktura i snabdevanje osnovnim životnim namirnicama. Prikazani su izvori mogućih neželjenih događaja usled nezgoda, nesreća, tehničkih grešaka, kvarova, prirodnih nepogoda i uticaja ljudskog faktora. Detaljno su objašnjene prevencija i predikcija ovih događaja.

Uvod

Kritične infrastrukture su toliko važne da njihova destrukcija ili zaustavljanje rada može imati ogromne posledice po nacionalnu bezbednost, ekonomiju, životnu sredinu i ljude. Kritična infrastruktura odnosi se na sredstva, sisteme, komunikacione mreže, procese i lance snabdevanja koji, ukoliko su uništeni ili privremeno onesposobljeni za rad, mogu znatno da utiču na dobro stanje nacije. Prekid rada kritične infrastrukture može da rezultira ogromnim gubicima života, da ima različite ekonomske efekte, itd.

Zaštita kritične infrastrukture uključuje programe i aktivnosti vlade, regulatornih tela, naučnih institucija, korisnika i vlasnika, kako bi se smanjila *ranjivost usled neželjenog događaja. Ona, takođe, uključuje krizni menadžment za podizanje otpornosti kritične infrastrukture. Evropska unija usvojila je akcioni plan zaštite koji je baziran na prevenciji pojave incidenata koji mogu da naruše bezbednost kritične infrastrukture, detekciji i odgovoru na krizu i međunarodnoj saradnji. Kritične infrastrukture u EU su delatnosti, mreže, usluge, materijalna dobra i informacione tehnologije čiji bi kvar ili uništenje znatno uticao na zdravlje, ekonomski prosperitet i ekonomiju vlada država članica. Nacionalne kritične infrastrukture su sistemi, mreže i objekti od nacionalnog značaja koji mogu imati uticaj i ozbiljne posledice na zdravlje i živote ljudi i ekonomsku stabilnost država članica. U Velikoj Britaniji, Švedskoj, Holandiji i Švajcarskoj primarne infrastrukture su telekomunikacije, u Nemačkoj je dodata i komunikaciona infrastruktura, koja važi i za Australiju i Kanadu koje su uključile i masmedije. Kritične infrastrukture u SAD su elektroenergetski sistemi, telekomunikacije, skladištenje nafte i gasa, bankarstvo i finansije, prevoz, sistem snabdevanja vodom, hitne službe, kontinuitet vlasti, informacije i komunikacije.*

U skladu sa navedenim, kao i principima dobre prakse, u ovom radu su prikazane sledeće kritične infrastrukture: elektroenergetski sistemi, mreža distribucije i snabdevanje energentima, proizvodnja, promet i skladištenje opasnih materija, saobraćaj i transport, informaciono-telekomunikaciona infrastruktura i snabdevanje osnovnim životnim namirnicama.

Elektroenergetski sistemi

Elektroenergetski sistem jedan je od najkompleksnijih svetskih sistema. Napajanje električnom energijom utiče na društvo i ekonomiju i izaziva domino efekat, ukoliko dođe do prekida napajanja. Zaštita ove kritične infrastrukture podrazumeva zaštitu njenih funkcija od fizičkih i elektronskih pretnji, na način koji je u skladu sa odgovarajućim procenama rizika. Prvo se proveravaju izvori rizika koji mogu biti tehnički, prirodni ili izazvani ljudskim faktorom, a zatim se proverava uticaj mogućeg rizika na funkcionisanje elektroenergetskog sistema. Za zaštitu se koriste uređaji da se spreče oštećenja u slučaju kvarova, mehanizmi za prekid rada električnih kola, zaštitni releji, zaštitne komore i veliki sistemi tipa SCADA.

Električna energija nastaje u hidroelektranama,,termoelektranama ili nuklearnim elektranama. Mreže za proizvodnju električne energije sastoje se od distributivnog sistema, podstanica, informaciono-telekomunikacionog sistema i drugih sistema i opreme potrebnih za održavanje elektroenergetskog sistema. Bezbednost u proizvodnji i distribuciji električne energije bazira se na primeni otpornog sistema, uz kombinaciju aktivnih i pasivnih mera bezbednosti.

Snaga vode, vetar, Sunčeva energija, biomasa i geotermalna energija takođe mogu da proizvedu električnu energiju, s tim što su to obnovljivi izvori energije, koji ne zagađuju okolinu i ne izazivaju efekat staklene bašte.

Izvori energije i snabdevanje

Energetski stabilnost je tema rastuće svetske zabrinutosti, jer veliki broj država nema svoje izvore energije već energetsku stabilnost obezbeđuje iz drugih država koje su često na nestabilnim područjima.

Ekonomski i ekološki najprihvatljiviji energent je gas. Gasovodi i snabdevanje gasom obuhvataju proizvodnju i distribuciju gasa distributivnom mrežom do potrošača, uključujući prodavce i posrednike, a isključujući vađenje zemnog gasa, rad koksnih peći, proizvodnju derivata nafte, itd. Za priključenje na gasovod potrebni su kućni priključak, mernoregulacioni set, instalacija u objektu, gasno trošilo i gasno brojilo. Za nadležnosti su odgovorne komunalna i sanitarna inspekcija, i protivpožarna policija. Ove službe su elementi preventivnih mera, uz striktno poštovanje tehničkih propisa za izgradnju gasovoda, razvodnih i distributivnih mreža i kućnih priključaka.

U ukupnoj strukturi proizvodnje naftnih derivata dominira proizvodnja motornih goriva, lož-ulja, i dr. U objektima za trgovinu naftom i naftnim derivatima neophodno je poštovati minimalne tehničke uslove u pogledu prostora, opreme, uređaja i načina prodaje. Zaštita se izvodi na sledeći način: stanica za snabdevanje mora imati zatvoren i otvoren deo, podloga mora da bude izgrađena od čvrstih materijala, prostor dobro osvetljen, a pumpni automati jasno obeleženi i povezani sa rezervoarima za istakanje. Skladištenje nafte, derivata i biogoriva u direktnoj je vezi sa trgovinom, pa privredni subjekti koji se bave ovom delatnošću moraju posedovati odgovarajuće licence. Uslovi za dobijanje licenci su rigorozni u pogledu mera bezbednosti.

Čvrsta goriva koriste se za proizvodnju električne energije u termoelektranama, poljoprivredi, industriji, toplanama, za grejanje i u domaćinstvima kao ogrevno gorivo. Sagorevajne čvrstih goriva ima veliki uticaj na život i zdravlje ljudi i životnu sredinu. Sagorevanjem se u atmosferu izbacuju opasne materije kao što su oksidi sumpora i azota, ugljen-monoksid, leteći pepeo, organske materije i drugi elementi koji izazivaju efekat staklene bašte. Zaštitu od požara u industriji čine poštovanje procedura i obučavanje personala koji radi na utovaru, transportu, istovaru i skladištenju čvrstih goriva.

Proizvodnja, promet i skladištenje opasnih materija

Kritična infrastruktura koju čine hemijska industrija i proizvodnja i tretman opasnih materija deo su svake nacionalne ekonomije i prožimaju druge kritične infrastrukture. Opasne materije u toku proizvodnje, transporta, skladištenja i rukovanja mogu da budu opasne po zdravlje i životnu sredinu. U zavisnosti od hemijskih osobina, agregatnog stanja i stepena opasnosti opasne materije su grupisane u devet klasa (eksplozivne materije, gasovi, zapaljive tečnosti, čvrste materije, samoreagujuće materije i čvrsti desenzitivisani eksplozivi, materije sklone samozapaljenju i one koje u dodiru sa vodom emituju zapaljive agense, oksidirajuće materije i organski peroksidi, otrovne, infektivne, radioaktivne materije, korozivne materije i ostale opasne materije i predmeti). Rezultat proizvoda hemijske industrije jeste osnov drugih privrednih grana i mogu biti đubriva, hlor, itd. Problemi u hemijskoj industriji mogu izazvati velika zagađenja životne sredine, pa je bitno osigurati svaki proces od proizvodnje opasnih materija do njihove potrošnje. Pretnje i ranjivosti ovih sistema vezani su za potencijalne terorističke napade, hemijsko oružje ili proizvode koji mogu biti korišćeni kao oružje i dr.

Jedan od segmenata rizika od neželjenih događaja pri rukovanju opasnim materijama jeste i njihov transport. Opasne materije transportuju se i prevoze drumskim, železničkim, plovnim i vazdušnim putem, a za svaki tip transporta važe pravila za sprečavanje akcidenata. Postoje regulative koje moraju da zadovolje pošiljalac, prevoznik i primalac.

Skladištenje opasnih materija vrši se na način na koji se obezbeđuje maksimalna zaštita i najmanji rizik od povreda i ugrožavanja životne sredine, u skladu sa zakonom i propisima. Obavljaju ga kvalifikovana lica odgovorna za postupanje sa opasnim materijama. Skladište mora biti izgrađeno u skladu sa planovima, a prostor za skladištenje mora da ispunjava zahteve koji se odnose na vlažnost, temperaturu, vazdušni pritisak i osvetljenje.

Saobraćaj i transport

Ekonomija i kvalitet života zavise od saobraćaja i transporta. Kao i kod drugih kritičnih infrastruktura, kao što su snabdevanje vodom ili električnom energijom, značaj saobraćaja i transporta uočljiv je tek kad do problema dođe. Održavanje i zaštita ove kritične infrastrukture jedan je od ključnih preduslova za ostvarivanje privrednog i društvenog razvoja. Saobraćaj je privredno-uslužna delatnost u okviru koje se prevoze roba, putnici ili energija, u određenom intervalu između zadatih tačaka – destinacija. Transport je, na drugoj strani, organizovano kretanje prevoznih jedinica po zadatoj ruti. To je javna služba koja ima zadatak da zadovoljava potrebe društva. Saobraćaj je širi pojam od transporta.

Saobraćaj obuhvata pružanje usluga prevoza putnika i tereta u drumskom i železničkom prevozu, u prevozu plovnim putevima i vazdušnim putem, kao i pružanje usluga na terminalima i parkinzima, kao i skladištenje i manipulisanje teretom. Transportni deo kritične infrastrukture sadrži kopnenu infrastrukturu, vazduhoplovstvo, plovnu infrastrukturu i infrastrukturu železnice. Jedan od bitnih elemenata ovog sistema je i poštanski transport.

Mostovi, vijadukti i tuneli su kritične tačke saobraćaja i transporta. Zaštita se izvodi izgradnjom elastičnih mostova, ugrađenim sigurnosnim sistemima, itd. Aerodrom je, takođe, visokorizična infrastruktura na koju mogu uticati prirodne nepogode, nesreće, pandemije, nemiri u državi, terorizam, rat i slično. Ono što je najbitnije u zaštiti aerodroma jeste da se obezbedi kontinuitet operacija u toku neželjenog događaja prevencijom, pripravnošću, odgovorom na krizu, ublažavanjem posledica krize, oporavkom i rekonstrukcijom. Brza reakcija na događaj je zadatak tima za brza dejstva koji treba da obezbedi normalno poslovanje na aerodromu.

Informaciono-telekomunikaciona infrastruktura

Komunikacije, energija, transport, vodosnabdevanje i druge kritične infrastrukture zavise od računarskih mreža koje su ranjive na maliciozne napade. Sve prednosti koje nudi savremena informaciona tehnologija istovremeno predstavljaju izvor potencijalnih napada.Telekomnikaciona mreža je skup resursa koji omogućuju prenos podataka na daljinu. Komponente telekomunikacione mreže su čvorovi, pristupna oprema i spojni *put, jezgro mreže i krajnji sistem i sistem za nadzor i upravljanje. Telekomunikacioni sistem čine hardver, softver, komunikacioni kanali i podsistemi za prenos podataka između lokacija. Sistem sadrži aktivnu opremu (svičevi, ruteri, centrale, oprema za bežičnu komunikaciju, optički konvertori) i pasivnu opremu (optički i bakarni kablovi, antene, utičnice).*

Informaciono-komunikacioni sistem, koji čine personal, hardver, softver, žične i bežične mreže i prateća oprema, imaju svaki svoju ulogu u prenosu podataka i informacija između korisnika ili između drugih sistema. Struktura sistema ukazuje na dve grupe ranjivosti: fizičke pretnje po arhitekturu, hardver i napajanje i sajber ugroženost informacionih procesa i odlučivanja, sistema za podršku i usluge. Potpuna zaštita ovih sistema nije moguća, ali je dobro primeniti mere prevencije planiranjem, odgovorom na incidente, upravljanjem neželjenim događajima i kontinuitetom poslovanja. Štite se mrežni nivo, operativni sistemi, aplikacije, baze podataka i procedure. Kod komunikacije treba odrediti mere autentikacije, autorizacije, kriptozaštite, neporecivosti, itd. Napadi mogu biti pasivni ili aktivni, unutrašnji ili spoljašnji. Najpoznatiji su DoS, Phishing, Botnet, Spam, Sniffing, Spoofing i maliciozni softveri tipa virusa, crva ili trojanskog konja.

Snabdevanje stanovništva osnovnim životnim namirnicama

Snabdevanje osnovnim životnim namirnicama zavisi od transporta, energije, proizvoda hemijske industrije i slično. Čine ga proizvodnja i prerada prehrambenih proizvoda i stoke, farme, objekti za preradu i skladištenje hrane i vode.

Promena u snabdevanju stanovnika vodom izaziva prestanak rada privrede, zabrinutost građana, smanjenje higijenskih uslova i slično. Sektor vodovoda osetljiv je na niz mogućih napada kao što su kontaminacija smrtonosnim agensima, fizički napadi, ispuštanje toksičnih gasova i drugo. Rezultat napada su žrtve ili bolesni i prestanak bazičnih usluga tipa rada bolnica, pripreme i prerade hrane, itd. Vodovod je moguće zagaditi na četiri nivoa infrastrukture.To su: izvorišta, sistemi za transport sirove vode, postrojenja za prečišćavanje vode i distributivna mreža. Zaštita se izvodi prevencijom, kontrolom, održavanjem, izgradnjom nove i rekonstrukcijom postojeće distributivne mreže, održavanjem kvaliteta vode, itd. Kvalitet vode utvrđuje se pregledima inspekcije i utvrđivanjem mikrobioloških i fizičko-hemijskih faktora i pokazatelja.

Proizvodnja, distribucija, skladištenje i snabdevanje hranom je kritična infrastruktura čiju osnovu čine nabavka sirovina, gajenje poljoprivrednih kultura i stočnog fonda, proizvodnja, prerada i pakovanje, skladištenje i transport, kao i distribucija gotovih proizvoda ili poluproizvoda. Zaštita se izvodi u lancima snabdevanja hranom za životinje i proizvodima životinjskog porekla, biljnim proizvodnim lancima, i u onim komponentama infrastrukture koje podrazumevaju preradu, proizvodnju, pakovanje, skladištenje i maloprodajnu distribuciju. Fokus je u zaštiti uskladištene hrane od hemijske, biološke, radiološke ili nuklearne kontaminacije. Zaštita se izvodi analizom rizika, monitoringom i revizijom, uzorkovanjem, nadzorom nad prometom hrane, nadzorom u fazama proizvodnje, hitnim merama, itd.

Zaključak

Kritične infrastrukture imaju značajnu ulogu u nacionalnim strategijama mnogih država, pa se sve više pažnje posvećuje zaštiti ovih ranjivih sistema. Strategije zaštite kritičnih infrastruktura postale su strategije održivosti vlasti, ekonomske stabilnosti, prosperiteta, industrije, zdravlja stanovništva i zaštite životne sredine. Dve decenije najznačajnije kritične infrastrukture bile su elektroenergetski sistemi, prevoz, snabdevanje vodom i hranom, poljoprivreda i vitalna industrijska postrojenja. U savremenom svetu kritične infrastrukture su postale i informaciono-telekomunikacione tehnologije, masmediji, bankarstvo i finansije,kao i životna sredina.

Svaka država određuje svoje kritične infrastrukture u skladu sa zahtevima njene nacionalne politike. Zajednice država, kao što je EU, imaju određene kriterijume za zajednicu, dok svaka nacija može da proceni svoje kritične infrastrukture. Rezultati iz prakse pokazuju da su najčešće kritične infrastrukture elektroenergetski sistemi, izvori i snabdevanje energijom, proizvodnja, transport i skladištenje štetnih materija, saobraćaj i transport, informaciono-telekomunikaciona infrastruktura i snabdevanje osnovnim životnim namirnicama.

U zavisnosti od tipa infrastrukture, pretnje kritičnim infrastrukturama mogu se podeliti u dve grupe: fizičke pretnje i maliciozni (sajber) napadi. Fizičkim pretnjama izloženi su uglavnom cevovodi, podstanice, skladišta, komunikaciona infrastruktura i industrijska postrojenja za preradu vode. Sajber pretnjama ugroženi su sistemi za nadzor i upravljanje, baze podataka, operativni sistemi, softver, automatizovane proizvodne hale i slično.

Ranjivosti kritične infrastrukture određene su njenim funkcijama. Kod elektroenergetskog sistema ranjivi su generatori, distributivna mreža i informaciono-telekomunikacioni sistem. Kod izvora energije štite se gasovodi i naftovodi, proizvodni procesi i skladišta, a u proizvodnji i oblasti tretiranja opasnih materija štite se proizvodi, transport i skladišta. U saobraćaju i prevozu ranjivi su transportna mreža, posebno aerodromi, mostovi i tuneli. Informaciono- telekomunikacioni sistem ranjiv je na dva nivoa: fizičkom i nivou komunikacija, dok su u oblasti snabdevanja osnovnim životnim namirnicama ranjivi proizvodnja, snabdevanje i skladištenje poluproizvoda i proizvoda.

Zaštita kritičnih infrastruktura izvodi se u zavisnosti od pretnji i ranjivosti, za sve delove kritičnih infrastruktura ponaosob. Neophodno je da postoji procena rizika i da personal bude adekvatno edukovan. Fizička zaštita sistema izvodi se ograđivanjem, čuvarima, blokadama ili odvajanjem proizvodnih procesa zbog domino efekta. Zaštita od sajber napada je bitna u svim onim delovima infrastrukture koji su kontrolisani računarskom mrežom, povezani na internet ili su bazirani na automatizovanim proizvodnim procesima.

Ključne reči: *saobraćaj, zaštita, ranjivosti, pretnja, kritična infrastruktura, hazardi.*

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СТРУЧНИ ЧЛАНЦИ
ПРОФЕССИОНАЛЬНЫЕ СТАТЬИ
PROFESSIONAL PAPERS

OPEN LOOP CONTROL OF THE FIVE-AXIS MISSILE AND TARGET FLIGHT MOTION SIMULATOR IMPLEMENTATION

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Summary:

An important phase in missile systems development is flight testing and simulation in the environmental conditions dictated by the operation the system is made for. Since field testing of complex systems means a big financial burden and a time consuming process, hardware in the loop (HIL) simulations represent a very effective solution for saving both costs and time. This paper presents an implementation of a control application that integrates synchronized data generation and acquisition on the five-axis missile and target flight motion simulator owned by the HIL laboratory. The described simulation application is a result of a missile development engineer's need for a simple way to acquire information on a real missile response, when desired control signals are provided. The solution is realized in LabVIEW software using a robust software design architecture named "classic state machine".

Key words: *tests, simulations, missiles, data acquisition, signal generation, state machine, synchronized measurements, LabVIEW, hardware in the loop.*

Introduction

Surface-to-air missile systems are developed to meet specified tactical and operational requirements in environmental conditions dictated by the operation itself. From the initial formulation of the concept for a new missile system to the end of the life cycle of the missile, there is a continuous need to predict the performance of alternative designs of the missile. It is important to emphasize that computational modelling and simulations with a set of partial differential equations bring uncertainty and errors when switching to realistic application (Oberkampf, DeLand, Rutherford, Diegert, Alvin, 2001). This happens because it is not easy to incorporate all environmental interactions into a mathematical model. That is why the most valuable source of information is missile field testing followed by missile flight simulation (USA, Department of Defense, 1995). Since field testing presents enormous financial cost, especially in the missile development domain, where field testing means a destruction of a missile itself, hardware in the loop simulations have proven to be a very cost-effective solution. Also, there is more pressure nowadays to get products to market faster and to reduce design cycle time. This has led to a need for dynamic testing, where components are tested while in use with the entire system, either real or simulated, with real-time hardware and software. A missile flight simulation is a way to find the missile performance under varying dynamics that is impossible to find by flight tests or by an analytical solution, so even nowadays this is a hot research topic (Awad, Wang, 2014). So, hardware in the loop (HIL) simulations become an integrated part of the design and testing cycle (National Instruments, 2008).

The simulation application described in detail in this paper is a result of a need of missile development engineers for a simple way to acquire information on a real missile response when desired control signals are provided.

HIL simulations

A hardware-in-the-loop simulation enables a highly realistic simulation of equipment in an operational environment. A typical HIL system includes sensors to receive data from the control system, actuators to send data, a controller to process data, a human-machine interface (HMI) and a development post simulation analysis platform (National Instruments, 2008).

Hardware in the loop laboratory, shown in Figure 1, is specialized for the HIL simulation of missile guidance and control systems, with real hardware, data acquisition, and signal processing.

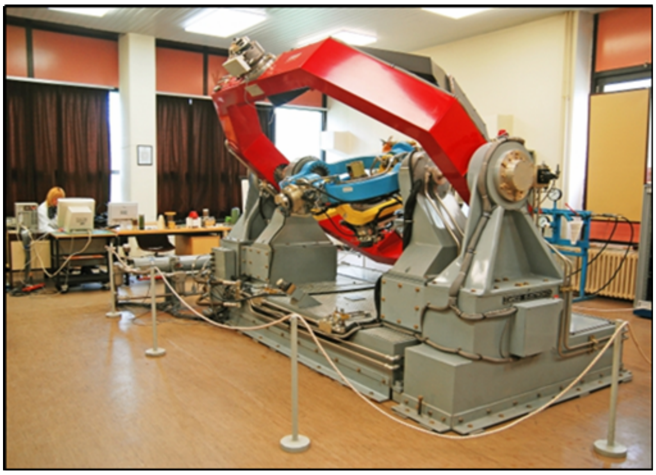

Figure 1 – HIL laboratory with five axis missile and target flight simulator
Рис. 1 – ПАМ Лабораторный пятиосевой имитатор движения ракеты и цели
Slika 1 – HIL laboratorija sa petoosnim simulatorom leta rakete i cilja

The laboratory is equipped with an S-450R-5 five-axis missile and target flight motion simulator, as well as measurement, data acquisition and signal processing systems (National Instruments, Data Translation). All Series S-450R-5 Flight Motion Simulators include a control console, hydraulic power supply with supply and air installation for high pressure working. A HIL simulation enables a development of appropriate testing and evaluation methods of guidance as well as a control systems simulation in a closed loop. Yaw, pitch and roll motions of a missile are realized by the inner three axes of the simulator. The outer two axes of the flight simulator provide the azimuth and the elevation of translational motions of the target (Acutronic, 2011). A HIL simulation is necessary in order to determine important technical and operational parameters of guided missiles. Since field testing is expensive, the usage of simulation software and hardware platforms ensures savings in guided missile and unmanned aerial vehicle (UAV) development.

LabVIEW technology introduction

LabVIEW is graphical programming language with its own development environment. Numerous NASA scientists and engineers all over the world use the LabVIEW language as a basis for instrument control, data acquisition, display, and data storage operations. With recent releases, LabVIEW has evolved from an instrument control and data acquisition tool to a general-purpose software development system that can be employed for nearly any application. Additionally, the ability to interface the LabVIEW source code and applications with other programming languages (such as Visual Basic and Matlab) means that software engineers can employ a combination of their favorite tools and development environments while working on any project (Don, Bradford, David, Hollis, Wei, 2001).

Problem overview and solution

The five-axis flight motion simulator is designed for high dynamic testing and evaluation of small to medium sized missile guidance systems (Don, Bradford, David, Hollis, Wei, 2001). In our case, the testing consists of specifying and giving control command signals and system response data acquisition. The given command signals are the parameters of a desired missile flight, all written in a textual document. Then, the data is processed and all the missing data is interpolated for purpose of adjusting to application, system and measurement requests. In the end, a system response is acquired and saved. It is necessary to have real time measurements and that is why there is a demand for synchronized command execution and data acquisition, which means synchronized output data generation and input data acquisition. For this realization, the chosen hardware is a National Instruments NI USB 6259 data acquisition device and the software is National Instruments LabVIEW v14.0. The acquired electrical signals are saved and available in the most convenient form for further analysis.

Global application structure and flowchart

Testing and measuring the structure organization is explained in the following paragraph. Control command signals are given through the PC application software written in LabVIEW programming language. A PC is connected via USB to the data acquisition device NI USB 6259. Analog inputs and outputs of the device are connected to corresponding inputs and outputs of the flight motion simulator. This hardware configuration is shown in Figure 2.

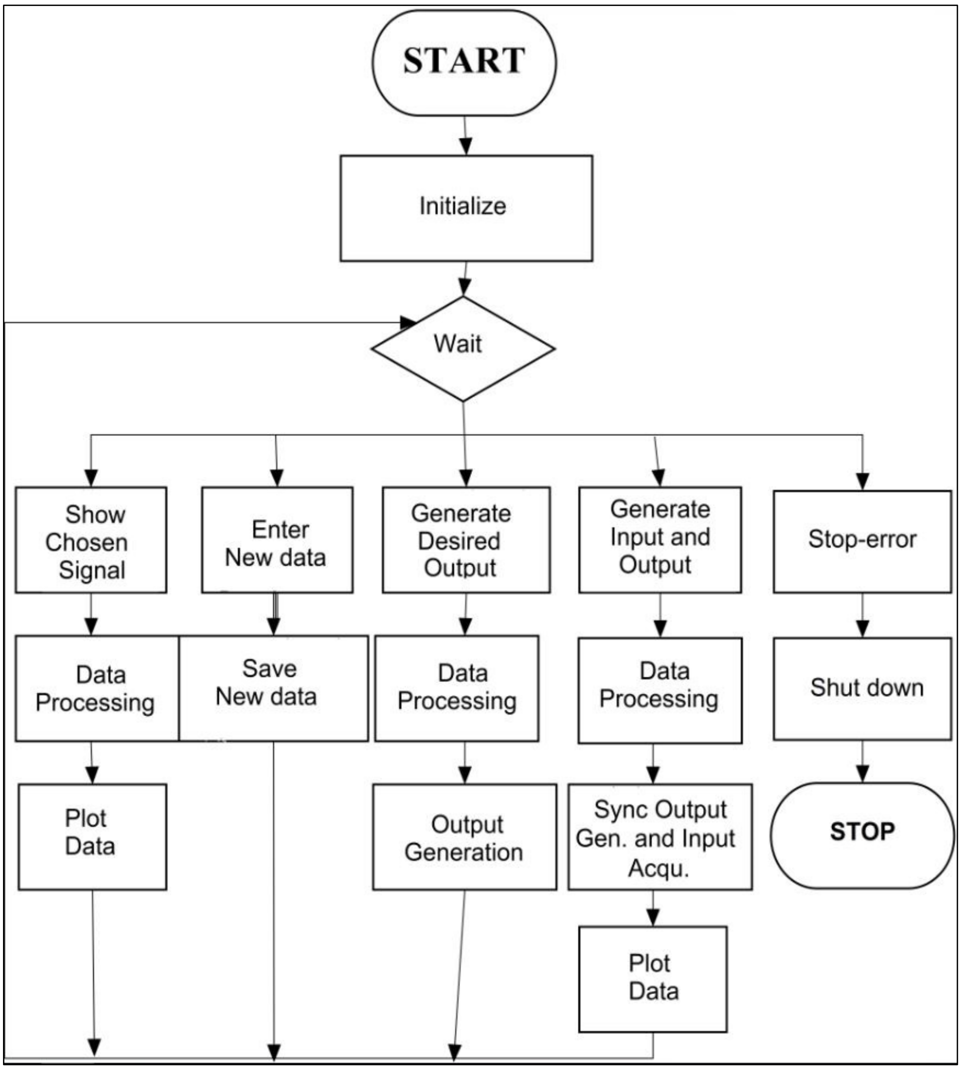

Figure 2 – Hardware configuration of the presented solution
Рис. 2 – Конфигурация оборудования представленного решения
Slika 2 – Hardverska konfiguracija predstavljenog rešenja

The main application flowchart is shown in Figure 3. The program options are: show control command signal, set new parameters, control commands generation, control commands generation and response data acquisition. As it can be seen in the flowchart, except for the main structure, there are also important subroutines (sub VI) explained in detail in the next paragraphs.

Figure 3 – Main flowchart
Рис. 3 – Диаграмма набегающего потока
Slika 3 – Dijagram toka glavnog programa

User Interface

The main task is to control the five-axis flight motion simulator, where control data is given in a textual document, and to acquire missile response data. The user interface is in Figure 4.

The simulator is controlled by the user through the main application window, which means that commands are sent to analog outputs and analog input data is acquired. The user has an option to choose the file for signal generation (which is sent to the analog output) and also to change general settings. As control command signals sent to analog outputs have to be adjusted to appropriate channel voltage levels, there are some additional settings (scale factors) for analog outputs. Possible actions for the user are: set new parameters, show signal waveform graphs, control commands generation, control commands generation and response data acquisition. The user can set and save new general parameters, or use saved values from the last measurement. Before signal generation and acquisition, the user is able to see signal waveform graphs. If there is a need to generate signals without acquisition, there is an option for this action, too, with its own interface.

By choosing the signal generation and acquisition action, the user gets synchronized signal generation and data acquisition. Simultaneous measurements involve different operations happening at the same time, such as data acquisition on the input channels while generating data on the output channels. However, these operations are not necessarily correlated to one another. Synchronized measurements, on the other hand, all need to start at the same time, as well as to share a common clock for latching data among all measurements (National Instruments, 2012).

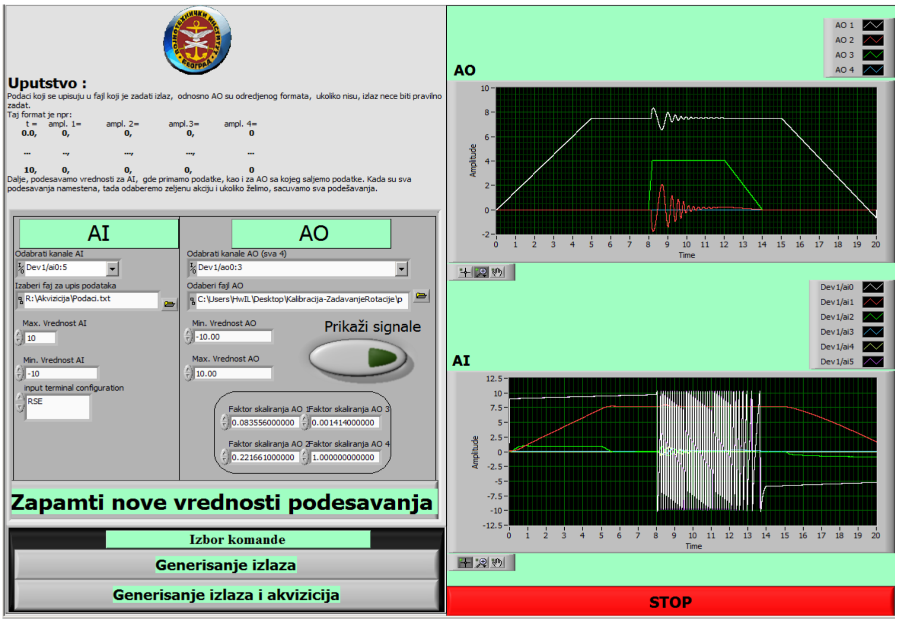

Figure 4 – User interface main window
Рис. 4 – Главное окно пользовательского интерфейса
Slika 4 – Glavni prozor korisničkog interfejsa

The data that the user wants to send to the simulator is in a form of textual files containing commands and corresponding time samples. The first step is to unpack the file and adjust the data for further processing in LabVIEW. Since the data is raw, which means not prepared for processing, very often it happens that time samples are not equidistant. Therefore, there is a need for the interpolation of missing data, with a previously chosen sample rate. Afterwards, the data is scaled, in order to adjust to channel voltage levels defined in the device data sheet. The processed data can now be sent to the outputs. The data acquired from the analog inputs is also saved in a form of text files, for easier analyses in any software package the user wants to use. The analysis can be conducted directly, in LabVIEW software with addition of one more subroutine for data analysis, but this request was not defined by the user. The user requirement was to pack the acquired data in a proper form to ensure an easy analysis in any kind of software used by engineers.

Software architecture

The main flowchart is shown in Figure 3. The used architecture is a classic state machine. The state machine translates state transition diagrams into a LabVIEW code that is readable, scalable and maintainable.

This way, the virtual instrument (VI) is organized into states which are general functions and features of application, and transitions that map out the ways that the VI can move from one state to another (Bress, 2013).

The described application has seven states. The states are defined based on application functional requests in a way that each state is independent and has a different function. The basic states that every variant of the state machine architecture must have are: initialize, wait and shutdown. When the application is started, the first state is “initialize state” which initializes all controls and variables. Then, the “in wait state” application waits for the user to select an action. The “shutdown state” shuts down the application due to error or stop the button click. The requested software functions, as it can be seen in the flowchart in Figure 3, are control command signal waveform graph, add new settings parameters, output generation, output generation and input data acquisition.

The basic states have a classic architecture which is almost the same for every state machine design, while functional application states have complex structures with additional subroutines, which differ from case to case. In the flowchart diagram it can be seen that, for the states control command signal waveform graph, output generation, output generation and input data acquisition, there is mutual action data processing, organized in one subroutine. This subroutine consists of unpacking textual document with desired control commands and time samples, adjusting the data for further processing, interpolation and scaling. The next integral part is a subroutine for settings parameter adding and saving. The output generation is a subroutine with its own interface. In the end, we have output generation and input data acquisition as a subroutine with its own interface, which enables synchronized output generation and input data acquisition. This is how the state machine with an error cluster data flow was formed.

Conclusion

This paper presents an implementation of a modern missile parameter testing method by using a robust software design architecture. The main advantages of this application are: it is easy to use, hardware support is compatible with software development environment used, so the probability of having hardware to software communication problems is very low and that leads to the conclusion that the testing process itself demands less time spent testing and preparing for it. The application is developed completely in accordance with the user requests, processes and saves the data in a form defined by the user. This software architecture design is readable and clear and the consequences are fewer problems with software inheritance which is certainly an advantage

The described solution is only the beginning of further automation, modernization and simplification of the flight simulation process using the five-axis flight motion simulator. The goal is to have a completely software control of the simulator axis, to be precise, its sensors and actuators, with additional applications for different HIL laboratory users. The main challenge for HIL simulation applications is the synchronization of a very large number of such I/O functions at high speeds and the rapid conversion of signal data to and from information for inputs and outputs, respectively. With the power and flexibility of today's computers, engineers and scientists are increasingly upgrading platforms for HIL simulations, so the future solution certainly means more powerful platform hardware configurations (National Instruments, 2008). The main interest of the HIL laboratory, as a part of the Military Technical Institute, for achieving this goal is cost reduction in missile systems and UAV development, as well as decreasing development time.

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ВНЕДРЕНИЕ СИСТЕМЫ УПРАВЛЕНИЯ ПЯТИОСЕВЫХ ИМИТАТОРОВ ПОЛЕТА РАКЕТЫ И ВОЗДУШНОЙ ЦЕЛИ В РАЗОМКНУТОМ ЦИКЛЕ

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ОБЛАСТЬ: електротехника
ВИД СТАТЬИ: профессиональная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

Важнейшим фактором в развитии ракетных систем является этап моделирования и симуляции движения ракеты в соответствующих операционным параметрам условиях. Учитывая высокую стоимость полевых испытаний подобных систем, большие финансовые расходы и продолжительность подготовительных мероприятий, симулирование в рамках программно-аппаратного моделирования (Hardware in the loop - HIL) является наиболее эффективным испытательным решением.

В данной статье описан процесс внедрения системы управления, то есть, синхронизированного генерирования и активации данных пятиосевого имитатора движения ракеты и воздушной цели, разработанного в лаборатории программно-аппаратного моделирования. Описанное в работе приложение имитатора обеспечивает эффективный контроль и безопасную среду, так как используя данную систему инженер-испытатель может сосредоточиться на функциональности устройства и быть уверенными в реальных параметрах движения ракеты. Решение разработано на платформе LabVIEW программного комплекса, с робастной архитектурой программного обеспечения, под названием «классический конечный автомат»

Ключевые слова: *испытания, моделирование, ракеты, сбор данных, генерирование сигналов, конечный автомат, синхронизированные измерения, LabVIEW, ПАМ.*

IMPLEMENTACIJA UPRAVLJANJA PETOOSNIM SIMULATOROM LETA RAKETE I CILJA U OTVORENOJ PETLJI

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OBLAST: elektrotehnika
VRSTA ČLANKA: stručni članak
JEZIK ČLANKA: engleski

Sažetak:

Razvoj raketnih sistema podrazumeva važne faze testiranja i simulacije leta rakete u uslovima okruženja koje diktira operacija za koju je sistem izrađen. Kako terenska ispitivanja ovako složenih sistema zahtevaju veliki utrošak finansijskih resursa, a i mnogo vremena, simulacije koje podrazumevaju hardver u petlji (Hardware in the loop – HIL) predstavljaju vrlo efikasno rešenje za smanjenje troškova razvoja i testiranja. U ovom radu predstavljena je implementacija upravljanja, odnosno sinhronizovanog generisanja i akvizicije podataka na petoosnom simulatoru leta rakete i cilja laboratorije za hardver u petlji (HIL *laboratorije). Opisana aplikacija za simulaciju javila se kao rezultat potrebe inženjera razvoja raketa za jednostavnim načinom akviziranja informacija o odzivu realne rakete na željena i zadata upravljanja. Rešenje je realizovano u LabVIEW softverskom paketu primenom robusne arhitekture softvera, takozvane klasične mašine stanja.*

Uvod

Kako su terenska ispitivanja ogroman finansijski trošak, pogotovo prilikom razvoja raketnih sistema čije poligonsko ispitivanje znači uništavanje same rakete, simulacije koje podrazumevaju hardver u petlji (Hardware in the loop – HIL) predstavljaju vrlo efikasno rešenje za smanjenje troškova.

HIL simulacije

Laboratorija za HIL specijalizovana je za poslove istraživanja i razvoja u oblastima simulacije sistema vođenja i upravljanja realnim hardverom i akviziciju i procesiranje realnih signala. Unutar laboratorije instaliran je petoosni simulator leta rakete i cilja S-45OR-5 sa sistemima za merenje, akviziciju i procesiranje signala. HIL simulacija omogućava razvoj pogodnih načina testiranja i evaluacije prototipova hardvera sistema vođenja i upravljanja raketom u zatvorenoj simulacionoj petlji. Simulacija kretanja rakete po visini, pravcu i valjanju obezbeđena je upravljanjem po tri ose. Spoljašnje dve ose simulatora predstavljaju azimut i elevaciju simuliranog translatornog kretanja cilja. HIL simulacija potrebna je radi određivanja neophodnih tehničkih i operacionih parametara vođenih raketa.

Pregled postavke problema i rešenje

Ispitivanje u konkretnom slučaju predstavlja zadavanje komandi simulatoru i praćenje, odnosno snimanje odziva sistema. Zadate komande predstavljaju parametre željenog leta rakete koji se zadaju u vidu tekstualnog dokumenta. Zatim se podaci obrađuju, interpoliraju oni koji nedostaju, odnosno izvršava se prilagođenje podataka traženim zahtevima sistema i samog merenja. Na kraju je potrebno snimiti odziv sistema. Neophodno je da se merenja izvršavaju u realnom vremenu, pa je zbog toga bitno obezbediti sinhronizovano izvršavanje komandi koje se šalju simulatoru i snimanje odziva, odnosno sinhronizovano generisanje izlaza i akvizicija ulaza. Za realizaciju je odabrana akvizicijska kartica National Instruments NI USB 6259, a kao softverski paket korišćen je National Instruments LabView v14.0. Akvizirani električni signali memorišu se i pakuju u format koji najviše odgovara kasnijoj obradi.

Zaključak

U radu je predstavljena implementacija savremene metode testiranja parametara rakete korišćenjem robusne arhitekture za dizajn softvera. Prednost opisane aplikacije jeste što je vrlo jednostavna za korišće-

nje. Pored toga, hardverska podrška je kompatibilna softverskom paketu koji se koristi, što sve dovodi do znatnog skraćenja vremena potrebnog za pripremu i izvršenje opita. Aplikacija je prilagođena traženim zahtevima korisnika, dakle obrađuje i čuva podatke u formatu koji je sam korisnik odredio, a zatim i vrši obrade nad podacima po zahtevanim kriterijumima. Još jedna prednost usvojenog rešenja jeste činjenica da je opisana i korišćena arhitektura dizajna softvera vrlo čitljiva i jasna, tako da se umanjuju problemi prilikom nasleđivanja softvera.

Opisano rešenje predstavlja samo početnu stavku u daljoj automatizaciji, modernizaciji i olakšavanju procesa simulacije leta rakete petoosnim simulatorom. Cilj predstavlja kompletno softversko upravljanje osama simulatora, odnosno svim njegovim senzorima i aktuatorima, sa dodatkom aplikacija po željama raznih korisnika ove laboratorije. Krajnji interes za ostvarenje zadatog cilja ove laboratorije, kao i samog Vojnotehničkog instituta kojem ova laboratorija pripada, predstavlja umanjenje velikih troškova razvoja, kako raketnih sistema, tako i bespilotnih letelica, a sa druge strane i uštedu vremena potrebnog za razvoj.

Ključne reči: *test, simulacije, rakete, akvizicija podataka, generisanje signala, mašina stanja, sinhronizovana merenja, LabVIEW, hardver u petlji.*

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EXPERT SYSTEM FOR MANAGING LOGISTIC PROCESSES

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Abstract:

The management of resources is one of the three most important areas of management in defense, besides the information management and the human resources management.

By defining the concepts of Information Systems, decision support systems, expert systems, as well as their component parts, the possibilities they offer and the way of their functioning, we have made an attempt to present the Logistics Information System as an Expert System. The growing importance and the need for fast, timely and continuous logistic support of military units imposes the need for introducing a computer automated system which will increase the work efficiency and will save time to managers and decision makers at all levels of the Command and Control in the Ministry of Defense of the Republic of Macedonia. Having accurate information in appropriate time, especially regarding the availability of material resources, is a prerequisite for effectively managing logistic processes and for successfully performing tasks by military units.

Key words: *information systems, systems, resources, military, manager, management of resources, logistics, information use, expert systems.*

Introduction

The management of modern business processes must constantly find solutions to all turbulence in the working environment and pay attention to developing one's own strategy in the area of: operations, automation, integration, information and utilization of resources.

Knowledge, information and achievements are an imperative of our time and a major precondition for success in the work of any individual or organization. Today, business entities are trying to communicate quickly and accurately to send all the information to necessary users.

This kind of needs exists in every sphere of the human activity: defense, science, technology, economics, arts, history, and more. The opportunity is available for instant access to information and its rapid exchange today, which is not a privilege of individuals or groups, but generally is a common good for everyone.

The rapid development of technology of computer systems created an opportunity of their participation in the transmission of information. Applications for this purpose are being developed in various fields of life. Modern scientific and technological development imposes a substantial change in the manner of data collection, processing and presenting.

The first rudiments of automated flow of information were made in the logistics system in the United States Army in terms of planning. The complexity of planning logistic support in multiple phase operations of modern armies overcomes the method of board and pen that was used before. Modern planning procedures depend on the use of automated programs to ensure their speed and to include all the details which have to match the pace of the operation (Edwards, 2004).

For quality management decisions, we need quality knowledge which is inherent to human experts. This knowledge can be included in the software for supporting decision making. Software that integrates the knowledge from experts is called a support system in decision-making based on knowledge (Knowledge Based Decision Support System - KBDSS) or an intelligent system for supporting decision-making (Intelligent Decision Support System - IDSS). Support systems for decision making based on knowledge can increase the capabilities for decision-making by supplying a software tool that will directly support the decision.

One of the main features of the decision-making process is based on information. Timely and accurate information is a key element and a prerequisite in the process of decision-making and the management of resources. Without the necessary information, data and parameters, it is impossible to make a decision.

A system for decision support is one of the most modern tools used in decision-making because it allows the integration of knowledge and experience of the decision-maker with the database, which facilitates the decision-making process.

The most commonly used software tools for supporting decision-making are expert systems. They are used in all areas of operation, in defense management as well, especially in providing logistic support. Logistics information management is a continuous process of: collecting, processing, preserving, analysing and presenting information on the course of the operation of the planned logistical support at all levels of command and control.

Modern logistics systems and processes are almost unimaginable without adequate information support. A huge amount of information which has to be processed daily, the need for quality management of resources and quick decision-making cannot be realized without work environment based on information technology. It supports the decision-making bodies and optimizes the management of logistic support.

The duty of all responsible authorities is to define precisely information objects (vehicles, persons, units, etc.), their characteristics that will be monitored and the form of reports which will be submitted to higher levels. The Logistics Information System as an expert system is a computer-supported system the goal of which is to support the management of logistic activities. It provides an opportunity for permanent optimization and improvement of working processes and the logistic support operation in general. Our aim is to present the logistic information system as an expert system, which is an important link in the decision-making process in the Ministry of Defense and the Army of the Republic of Macedonia.

Categories of research

Permanent social and technological development which attempt to promote and facilitate work imply the need to introduce information systems that contribute to speed, timely and accurate receiving, processing and distributing information to all levels of management.

In the following part of our paper, we will examine several categories relevant to the subject of research: information system, decision support system, expert system, management, logistics management and logistics information system.

The International Federation for Information Processing - IFIP defines the information system as follows: The information system is a system that collects, complements, stores, processes and delivers information relevant to the organization and society, in order to be available and usable by anyone who wants to use it, including the management, customers, employees and others.

The Information System is an active social system that may or may not have to use information technology (International Federation for Information Processing: Technical Committees and Working Groups-Information Systems, 2013).

The information system is a set of methods, procedures and resources designed to facilitate the achievement of certain goals (Thierauf, 2001).

In terms of the systematic approach, the information system is a sorted set of methods, processes and operations for: collection, storage, processing, transmission and distribution of data in one organization, including equipment used for these purposes and people engaged in these activities (Pojam informacionog sistema, 2013).

The information system should be placed in a way that: it will be understood by all users, will be simple in presentation of information, will be secure and will allow presentation of the processed information in a very short time interval.

There are different divisions of information systems. For example, some authors are dividing modern information systems in: operational information systems and systems for supporting decision-making in management.

Systems for decision support

Decision Support Systems-DSSs represent a powerful tool in making complex decisions and they are used in many fields, including defense. As an update of various disciplines, primarily management and information science, they have roots in the decision-making theory and are used in various areas of operation from natural sciences, technology, economics to education (Veljović, 2007, p.1).

Systems for decision support are supporting all stages in the decision-making process, starting with the stage of formulating the problem through the design phase and the phase of selection, to implementation. Furthermore, they support various processes and styles of decision-making, they are adaptive to new operating needs, easy to use, they enable greater efficiency in the decision-making process, etc. They also need to provide timely information to managers, which would also be accurate, relevant and complete. The information should be shown in a proper form in order to be easily understood and managed (Veljović, 2007, pp.1-2).

Many authors during their development had different interpretations of the term ‘system decision support’. Turban gives a very precise definition which, according to him, is: an interactive, flexible and adaptive computer-based information system designed primarily to support the solving of unstructured management problems for improving the decision-making process (Turban, 1995, p.5).

Expert systems

Expert systems in the artificial intelligence are computer programs designed to solve complex problems using reasoning based on expert knowledge which does not follow the procedures developed in the case of conventional programming (Turban, Aronson, 1988, p.15).

The appearance of expert systems has greatly facilitated the work at places where complex and important decisions are made. These systems represent computer programs that simulate the behavior of persons or organizations with expert knowledge and experience in a particular area. Typically, these systems contain a knowledge base which contains accumulated experience and a set of rules to change the basis of knowledge of each particular situation described in the program. Sophisticated expert systems can be improved by adding knowledge to the base or set of rules.

According to Edward Feigenbaum from Stanford University, one of the best experts in this area, who presents expert systems in the best way, uniting both of the above aspects, expert systems are intelligent computer programs that use the knowledge and procedures of locking to solve complex problems, which require human expertise and skill. The required level of knowledge along with locking mechanism for solving the problem can be considered as a model which is simulating the best expert in that area (Mišković, 2013, p.150).

Besides the general division of expert systems which are divided into those that analyze a problem and those which perform a synthesis in the process of solving the problem, the expert systems are distributed based on the type of information they offer, such as: independent, consulting and systems "would be if ..." (Mišković, 2013, p.139).

The key components of each expert system are: (Fig.1) knowledge base, deduction mechanism and user interface (King, 1989, p.21).

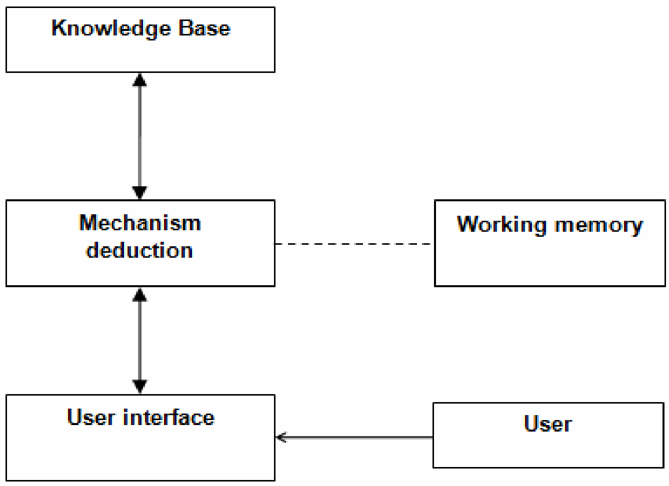

Figure 1 – The basic structure of expert systems
Рис. 1 – Базовая структура экспертной системы
Slika 1 – Osnovna struktura ekspertskog sistema

The knowledge base is the basis of the expert system and contains the necessary knowledge for understanding, formulation and problem-solving, which contains information and regulations for the specific problem area (real system) that we want to make. Besides general knowledge, it contains special heuristics - rules and subjective assessments that guide the knowledge.

A deduction mechanism has a task to find the right knowledge from the knowledge base and to develop new knowledge. It can be said that the mechanism of deduction is the most important activity which takes place in the expert system. Thanks to this activity, expert systems are intelligent systems. The process of locking is the one which animates the otherwise lifeless knowledge stored in the knowledge base and which knows how to apply it to the existing problems. Without the process of locking, expert systems would be only an Encyclopedia of information.

The user interface is the third major component of any projected expert system. The main role of this component is to provide simple communication between the system and the user, i.e. to provide the following: easy communication, simple running of the program, control of input and output and quality interpretation of results (King, 1989, pp.22- 23).

The process of expert systems functioning can be divided into the following five components: acquisition of knowledge, presentation / exhibition of knowledge, knowledge processing, interface components and explanation.

Management of logistics information

Management as a phenomenon is present in nearly every scientific discipline and covers all functions that successful functioning of society depends on. It represents a base of the modern approach to the management and training of organizations in a line with the long-term needs and requirements of the environment.

According to Shermerhorn (Schermerhorn, 2002), management is a process of planning, organizing, managing and controlling the process and use of resources to achieve the objectives. He provides a schematic view of the management process, shown in Figure 2.

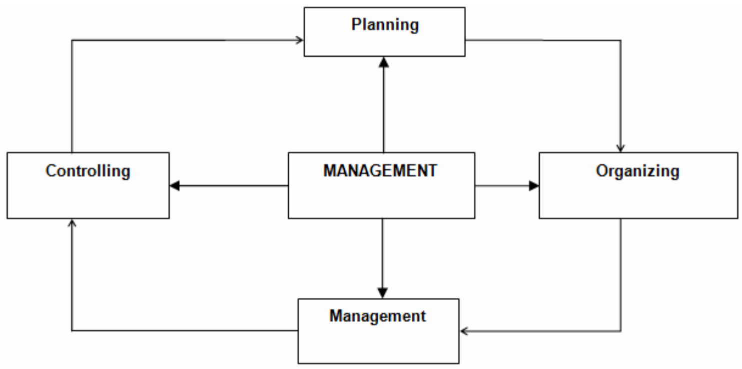

Figure 2 – Schematic representation of the process of managing
Рис. 2 – Схематическое изображение процесса управления
Slika 2 – Šematski prikaz procesa upravljanja

According to Woodruff and Thomas (Thomas, Woodruff, 1999), managers are responsible for four functions of the management process. Decision-making is the primary job of any manager, no matter the level or function. A decision is always a reaction to a situation, something that should be taken or needs to be changed. In order to make good decisions, managers must be familiar with modern methods and principles of decision-making. Modern managerial decision-making is based on scientific principles, quality information and effective assessment processes.

As we already pointed out, management is an essential feature of modern activity of any organization, including the Ministry of Defense and the Army of the Republic of Macedonia.

Logistic support management is a process that includes planning, decision-making, organization, cooperation and coordination, monitoring and reporting the implementation of logistic support. It is a segment in the overall system of defense management, implemented at all decision-making levels to optimize logistic support (Ministry of Defence of the Republic of Macedonia, 2011, pp.22-26).

The management of logistics information connects the information technology with logistics processes and enables the authorities to facilitate decision-making, delivering actionable information in real time, as well considering the actual needs for logistic support (Andrejić, et al., 2009, p.59). The management of logistics information should cover all logistic functions and should enable the link between them and with other functional areas in the defense; hence the need to introduce an information system in logistics or the Logistics Information System.

The logistics Information system is a computer-supported system which completely provides support in managing integrated logistic activities and management with the logistics system. Generating quality reports and timely information necessary for decision-making is the primary task of the logistics information system.

The mission of the logistics information system in the sphere of defense is seen in the planning, creation, development, monitoring, maintenance or continuous support of efficient and effective defense forces (Andrejić, et al., 2009, p.60).

Logistics information system as an expert system for managing logistics processes

Working with logistics information is a continuous process of collecting, processing, preservation, analysis and presentation of information on the course of operation of the planned logistic support at all levels. All this is aimed at supporting the decision-making bodies and at the optimization of logistics management support. The duty of all authorities is to define precisely the information objects (vehicles, persons, units) and their characteristics which will be monitored in the form of reports submitted to higher levels. The periodic and additional records, reports and collected information are in accordance with the needs and the available data.

Modern working processes, modernization of institutions, influences from developed countries, emerging challenges and trends show the need for keeping up with these developments in all spheres of society, including the sphere of defense.

The problems of today's working practices (characterized by outdated methods, business techniques, technology and systems, data inconsistency, poor visibility of fixed assets and supplies, lack of accurate information and slow flow of information) have imposed the necessity of introducing an automated information system that will satisfy the following needs and requirements: compatibility with the NATO standards, the need for accurate and timely data, precision in planning, budget versus reality, better consumption control, sustainable and proactive planning, procurement and monitoring of supplies.

In accordance with the Project for improvement of the Macedonian infrastructure and business services (MIESU - Macedonian Infrastructure and Enterprise Services Upgrade) two subprojects were initiated and conducted, related to: upgrading the infrastructure of Global Communications Information System (GCIS) and implementation of the application for the Logistics information system (The Government of the Republic of Macedonia, 2011, pp.4-5).

The aim of the project concerning the global information communication system was building new IT infrastructure and improving the existing one in the country for the needs of the Ministry of Defence and the Army of the Republic of Macedonia. Now the entire network and communications equipment and services are based on open standards and they are compatible with the existing global information infrastructure.

The purpose of the rest of the project was configuring, developing and constructing a logistics information system which will be implemented in the Ministry of Defense and the Army of the Republic of Macedonia. It is planned that this system consists of three subsystems: Information supply systems (ISS), Information maintenance system (IMS) and Information system for movement and transportation (ISMT).

These three subsystems will be developed successively. The first phase is currently being implemented, which is the development and implementation of the Information Supply System. This system provides support for managing materials, resources and requirements for procurement and supply of background material items for the Ministry of Defense and the Army.

The Logistics information system provides support for the automated information system for the following functional processes: forecasting and planning materials, requirements for the purchase of stocks, origin of supply, contracts, purchasing, receiving, inventory transfers between units, delivery / dispensing material items, requests for supply recharge and asset management.

These eleven procedural models are closely interrelated and there is a need for exchanging information. The interconnection between the processes is shown in the diagram below (Figure 3) in order to present the flow of information between each model.

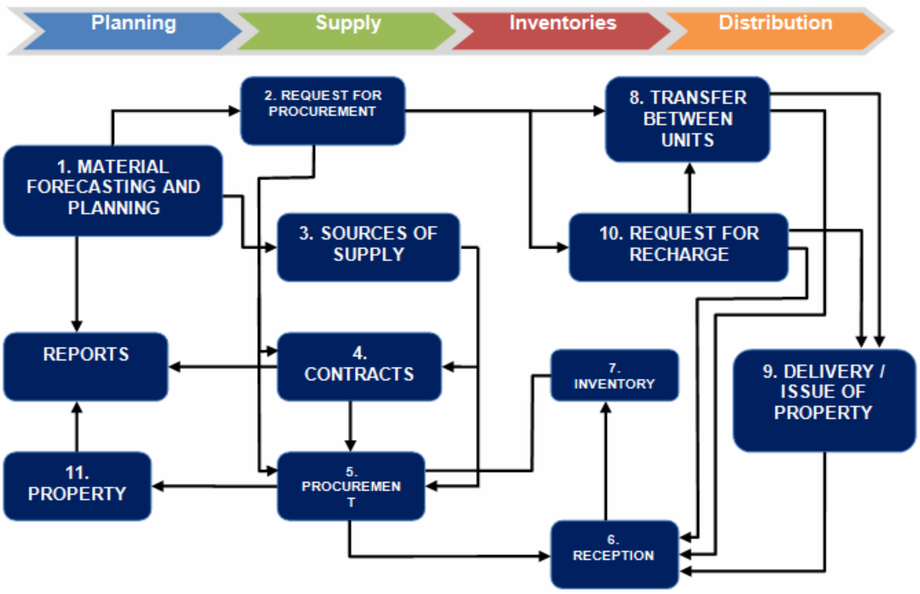

Figure 3 – Procedural areas of the Logistics Information System
Рис. 3 – Процессные области Логистической информационной системы
Slika 3 – Procesne oblasti Logističkog informacionog sistema

In the framework of the logistics information system based on the needs for accessing data and their analysis in daily operations, the key logistics customers are defined.

The logistics information system has led to changes in the performance of daily tasks of employees in the military, especially those involved in the logistics business processes. Documents and data which used to be processed manually and on paper now are stored electronically in the system for promoting greater efficiency and greater control.

It was already stated that the Logistics information system was based on eleven contractual process areas classified in three modules:

• From finance to control - module which is covering the business areas: integration with financial and material planning and forecasting;

• From procurement to payment - module which is covering the business areas: procurement requirements, sources of supply, contracts, procurement, requests for recharging;

• From admission to delivery - module which is covering the business areas: reception of materials, inventory transfers between units and issuing material delivery and asset management.

Additionally provided requirements are fuel and planning projects (Government of the Republic of Macedonia, 2010).

Let us remember that according to the definition, the expert system is a computer program that simulates the behavior of one person or organization that has expert knowledge and experience in a particular area. Indeed, this definition proves to be correct because the Logistics information system was created by experts whose expertise and experience it incorporated and transformed into a knowledge base which is the basis of this system.

Two groups of experts were involved in the creation of the Logistic information system. First, many experts from different fields: finance, supply management, logistics, procurement, cost management, warehouse management, etc. This group of experts created the user software Dynamics AX. The other group was composed of experts from the Ministry of Defence from the respective areas who incorporated their expertise and long experience to modify the Dynamics AX and to make an adequate knowledge base which is the basis for the Logistic information system.

In the time of establishing the system, the experts provided an opportunity for constant updating and modernization depending on the needs and requirements brought by the new era.

Benefits from the use of the Logistics information system

Logistics management is considered as a critical link in the process of defense management. For making better decisions and for proper management of resources, the necessary information is required to be timely and accurate. Due to the need for the codification of assets and compatibility of the domestic logistics system with the NATO systems, and the need for the accuracy of inventory planning, a project was launched for modernizing the way of working in the field of logistics which resulted in the decision to implement the Logistics information system.

The new Logistics information system has these sets of capabilities: development, construction, implementation and support of eleven agreed processes / modules, fuel management, export data to other systems, prototype of functionality for maintenance, repair and overhaul, as well as determining the needs for the module of transport and distribution.

The list of benefits from the implementation of the Logistics information system is remarkable, but, as some of the most important and greatest benefits, we will mention the following:

- speed and accuracy of data;
- efficiency in the functioning;
- interoperability with NATO;
- reduced operating costs;
- sustainable Logistics information system and architecture that is easy to upgrade;
- benefit on the national level, and others.

In the following part of our paper, we will give a short description for each of the benefits.

Speed and accuracy of data

The proper planning and forecasting of purposes are essential for the proper resource allocation and management of courses to ensure their rapid and accurate determination. Also an important element is the corresponding warehouses for storing goods providing tactical and strategic flexibility.

The Logistics information system has replaced the outdated system which consisted of a lot of data sources. Their inconsistency, poor visibility of the underlying assets and consumables were replaced with high precision in the planning process, improving the control over the consumption and, very importantly, the sustainable and proactive planning of procurement and monitoring of supplies.

Month-long data updates, slow flow and lack of accurate information are replaced with accurate and timely data given in the Logistics information system which maintains the accuracy in daily operations. All this in reality means that daily transactions in terms of material resources or material lists are transferred to a responsible person with one click, instead of spending time in a time-consuming process. All this affects the accuracy of data, because in real time we have precise data about what and where something can be found, going to the tiniest details, for example: Which shelf, room or building has what we are looking for.

Efficient functioning

Defense forces must be ready at any time to carry out their tasks and missions in a controlled manner, thereby avoiding unwanted situations of lack of exact quantity supplies, ammunition, food, fuel and spare parts. This system forms the basis for the efficient functioning of the armed forces in a way that enables decision makers at every level to have visibility of all necessary data.

Interoperability

The desire of Macedonia to become a NATO member and the change of the mission of the armed forces are leading to the needs for the Army to be flexible in terms of fulfillment of the standards. The system is designed to enable complete management of logistics defense processes and to allow a kind of transformation of the organization of the defense at the strategic level. The Logistics information system significantly improves the interoperability with allied Logistics systems and the codifing standards.

Reduced operating costs

The possibility of obtaining accurate data for the assets in each segment of the Army or unit, warehouse, etc, which contributes to more accurate creation of financial plans and, accordingly, the plans for procurement, which results in proper and economical use of the budget. With visibility of materials on inventories in warehouses, managers are allowed to perform restricted resources from the nearest storehouse, which leads to reduced costs in terms of movement and transport.

Sustainable Logistics information system and architecture that is easy to upgrade

The Logistics information system, as an expert system, is selected for use in the defense sector because of its scalable architecture that allows extensibility of processes, in addition to the latest trends of modernization and transformation of the Army.

After the implementation of the first stage, we have already seen a possibility of extending the decision for closing the gap for financial management, transportation and distribution and resources management of selected tracking assets as the next stages of our engagement.

The benefits at the national level

The state will have a possibility to implement advanced technology available from global partners, such as Hewlett Packard to identify, design and implement technology for transforming and extending the knowledge of employees in the government and in the military sector using the best practices and leading technologies.

Conclusion

In the decision-making process, it is important to consider alternative solutions, recognize possible consequences of their use and compare options. The process is further complicated with the external environment (new technologies, information systems, advanced research and globalization) and the fact that everything is becoming more and more complex.

Because of all the above reasons, managers are forced to use new techniques and tools for the decision-making process and they need to rely on information technology. Modern logistics systems and processes are unthinkable without adequate information support.

A huge amount of information which needs to be processed daily, the need for quality management of resources and quick decision-making, and the reduction of personnel in order to use resources more economically, cannot be realized without adequate support of a quality information system.

Today we spent less energy, time and personnel for processing simple information which would be adequately used in the process of decision-making from the lowest tactical to the strategic level.

With the introduction of the Logistics information system, we will have lower economic costs in the logistics support system. The rapid transmission of information, timely locating the needs of units, available data for the status of resources, affects on reduction of storage material assets in stocks (Andrejić, et al., 2009, p.15).

This application itself was a part of Microsoft software, specifically Microsoft Dynamics AX. This solution was chosen because of several key elements, such as: timing of implementation which entails reduced costs; the fact that it is an integrated ERP (Enterprise Resource

Planning)-solution concerning financial management, payment and purchasing, and supply chain of logistics; its flexible configuration (application which is global, but adapted to the Macedonian conditions), and in particular the important ladder architecture which allows the extensibility of processes and roles.

The last element relates to the intentions of the Ministry of Defense to integrate all functions of the Logistics system though different stages. Currently, the Logistics information system is in its first phase, which supports the supply area with their supplying subsystems.

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ЭКСПЕРТНАЯ СИСТЕМА МЕНАДЖМЕНТА В ЛОГИСТИЧЕСКОМ ПРОЦЕССЕ

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ОБЛАСТЬ: менеджмент в области обороны, логистика
ТИП СТАТЬИ: профессиональная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

Менеджмент ресурсов наряду с информационным менеджментом и менеджментом персонала является одной из важнейших областей управления в системе обороны.

В результате определения таких понятий как: информационная система, система поддержки принятия решений, модульная система экспериментов, и их составляющих, а также в результате исследований их возможностей и эффективности, предпринята попытка преобразования логистической информационной системы в экпертную систему управления.

Для быстрой, своевременной и бесперебойной логистической поддержки военных подразделений большое значение играет автоматизированная информационная система, повышающая эффективность работы и экономящая время менеджерам и командующим на принятия решений и мониторинг в Министерстве обороны Республики Македония.

Своевременное получение точной информации о наличии материальных ресурсов является главным условием эффективного управления логистическим процессом и успешного выполнения поручений, выданных воинскими подразделениями.

Ключевые слова: *информационные системы, системы, ресурсы, военные, менеджер, менеджмент логистики, преобразование данных, экспертная система.*

EKSPERTSKI SISTEM ZA MENADŽIRANJE LOGISTIČKIH PROCESA

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OBLAST: menadžment u odbrani, logistika
VRSTA ČLANKA: stručni članak
JEZIK ČLANKA: engleski

Sažetak:

Menadžment resursa predstavlja jednu od tri najvažnije oblasti za menadžment u odbrani, između informatičkog menadžmenta i menadžmenta ljudskim resursima. Preko definisanja pojmova informatički sistem, sistem za podršku odlučivanju, sistem za eksperimentisanje, kao i komponente koje ih sačinjavaju, mogućnosti koje nude i način njihovog funkcionisanja, učinjen je pokušaj da se prevede logistički informatički sistem u ekspertski sistem. Veliki značaj za brzu, pravovremenu i kontinuiranu logističku podršku vojnih jedinica nameće potrebu za uvođenjem informatički automatizovanog sistema koji će da poveća efikasnost u radu i uštedi vreme menadžerima i donosiocima odluka komandovanja i kontrole u Ministarstvu odbrane Republike Makedonije. Pravovremeno raspolaganje tačnim informacijama koje se odnose na raspoloživost materijalnih resursa predstavlja preduslov za efikasno upravljanje logističkim procesima i uspešno izvršavanje zadataka vojnih jedinica.

Ključne reči: *informacioni sistemi, sistemi, resursi, vojni, menadžer, menadžment resursa, logistika, koričenje informacija, ekspertski sistem.*

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NOISE AS AN EXTERNAL EFFECT OF TRAFFIC AND TRANSPORTATION

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Summary:

The paper deals with the basic concepts and characteristics of external effects of traffic and transport, with an emphasis on the impact of traffic noise as one of the main external effects of transport nowadays. The main negative impacts of traffic noise on human life and social activities are given as well as the causes of elevated levels of noise from road, rail and tram traffic. In addition, the paper provides a review of the common measures that can be applied to reduce the impact of noise generated as a result of traffic and transport activities. In the end, we made a short review of the current situation regarding the impact of traffic noise in the Republic of Serbia and the Serbian Armed Forces.

Key words: *traffic, noise.*

Introduction

The rapid development of industry and technology has undoubtedly led to a rise in the standard of living, which results in increased traffic activity. This is primarily related to passenger and freight road transport, but certainly to rail, water and air transport as well. However, as a part of comprehensive technical development, problems related to the preservation of the environment also increased. The increasing concentration of traffic activity in urban areas has the effect of endangering the working and living environment. The influencing factors are: pollution of air and working environment, noise and vibration, traffic accidents, uncontrolled discharge of harmful and hazardous substances, traffic congestion and crowds.

Noise is one of the major causes of a reduced quality of life, especially in urban environments where its constant presence and influence affect many aspects of everyday life. This is confirmed by the fact that damage to hearing due to noise is among the most prominent problems of professional pathology. If other effects of noise on human organism are added, it is clear what possible consequences noise can have. In today's world, traffic and transport are identified as one of the main noise sources. Accordingly, special attention should be paid to reducing the level of traffic noise; otherwise, there is a danger that the noise level would remain high or even increase. This is corroborated by the fact that the number of vehicles and kilometers traveled per vehicle are constantly increasing from year to year.

Consequently, it is necessary to significantly concentrate on both theory and practice to find ways of combating the harmful effects of traffic noise, i.e. to find measures by which people and their environment can be protected from them and that will allow the smooth progress of their working, social, recreational, creative and other activities.

A large number of health studies and scientific papers deal with the problem of noise impact on the quality of life such as the impact of road traffic noise on sleep and mental health (Belojević et al., 2015), (Bodin, et al, 2015, pp.1612-28), (Sygna, et al., 2014, pp.17-24), (Aasvang, et al., 2011), (Basner, et al, 2008), (Griefahn, et al., 2006), (Kishikawa, et al., 2009), the impact of air traffic noise (Hardoy, et al., 2004), (Schreckenberg, et al., 2010), and the impact of rail traffic noise on the quality of life and health of people (Aasvang, et al., 2008), (Aasvang, et al., 2011). Of course, measures and actions to reduce traffic noise are also research topics in the field of noise impact (Wijnant, Hooghwerff, 2015), (Yamamoto, 2015), (Paffen, et al., 2015), (Ganić, et al., 2015, pp.115-123).

External effects of transport

Efficient and well-developed transport systems contribute greatly to the smooth functioning of the economy and its development, increasing competitiveness, increasing employment, faster and better exchange of goods and services, as well as increasing mobility of people in order to achieve professional and social activities. An especially important strategic role of transport is reflected in its contribution to the developing of underdeveloped regions and their integration into the global economic mainstream. It is one of the most important factors in achieving the overall economic prosperity of a country and the economic welfare of its citizens. The specificity of the transport sector is also reflected in the fact that the benefits of the investment in the transport infrastructure are manifested not only in the transport sector but also in other economic sectors. However, despite the great importance of transport and its enormous contributions to the overall economic welfare, there are significant external effects which, due to their size and possible consequences, generate increasing interest.

In order to understand better the external effects of transport, it is necessary to examine the costs incurred in the transport sector and to make a clear distinction between internal and external costs, Table 1 (Kaplanović, 2012). For the calculation of total costs, in addition to internal ones, external costs should be taken into account. These costs are not borne directly by those who have caused them, but they are borne by other participants in transport (congestion, traffic accidents, etc.) as well as the society in general (environmental costs of pollution, noise, etc.). External transport costs arise when customers do not pay the total cost of transport operations carried out or when they do not receive the full benefit. In other words, external costs are created when the benefit of individuals is affected by the actions of others who do not take into account this influence during their activities (Kaplanović, 2012). This can result in the adoption of wrong decisions on the transport market, and thus in inefficient use of available resources.

Table 1 – Classification of costs in transport
Таблица 1 – Классификация затрат по транспорту
Tabela 1 – Klasifikacija troškova u transportu

The categories of costs	Social costs	
	Internal costs	External costs
Expenditure on transport	Costs relating to the vehicle and the fuel	Costs paid by others
infrastructure costs	User fees, taxes related to vehicle excise duty	Uncovered infrastructure costs
Costs of traffic accidents	Costs covered by insurance, own costs of traffic accidents	Uncovered costs of traffic accidents
Environmental costs	Own loss of benefits	Uncovered environmental costs
Cost of congestion	Costs of one's own time	Delays / time costs imposed on others

A large number of negative external effects are connected to transportation, the most important ones being: climate change, air pollution, congestion, traffic accidents, noise pollution, loss of land, generation of waste, vibrations, water pollution, etc. In addition, the negative impact is seen in degradation and fragmentation of land, disposal of used transport vehicles and other transport equipment, transport of dangerous goods, endangering the environment, etc. The basic categories of external effects, the types and characteristics of costs and the types of externalities are given in Table 2 (Pejčić, Bojković, 2012).

Table 2 – Overview of the most important external effects of transport
Таблица 2 – Перечень наиболее значимых непредвиденных эффектов транспорта
Tabela 2 – Pregled najznačajnijih eksternih efekata transporta

Type of effect	The most significant cost components	Type of externalities
Air pollution	The damage (cost) for human health and agricultural goods	Completely external
Traffic accidents	Additional costs (medical care, property damage, human resources)	Partly external (the part that is not covered by insurance)
Climate changes	Damage (expense) from global warming	Completely external
Congestion on the roads	Costs for additional time and exploitation	External for individual users, and internal distribution by sectors
Processes "up-and downstream"	Additional environmental costs (air pollution, climate change)	Completely external
Noise	The damage (cost) for human health and the reduction of the value of a potential residential exposed to noise	Completely external
Additional costs in urban areas	Costs in the form of additional time for separation and / or lack of space for non-motorized modes of transport	Completely external
Soil degradation due to construction of transport infrastructure	Additional costs of repairing the damage, the costs of compensation	Completely external

The costs of energy dependence, aesthetic consequences, waste generation, water pollution, vibration, land use, separation etc., are also external effects of traffic and transportation to which, however, less attention is now devoted.

Traffic noise

The impact of noise

The sense of hearing has a big impact on the overall condition of the human organism, in a physiological as well as psychological domain. It connects people with the environment and allows them to communicate with other people. In addition, hearing is the most sensitive and most important mechanism for warning against danger, because at any time humans receive impressions from the surroundings, regardless of whether they are awake or asleep. Noise is one of the leading problems in urban areas, because exceeding the permissible noise levels can significantly affect the quality of life. Noise can affect human health in many ways, causing nervousness, sleep disturbances, and disruptions in communication, reducing working capacity, leading to the consequences in social behavior, as well as to the loss of hearing. Also, noise can result in a disruption of daily activities, thus causing general discomfort, stress and frustration. Due to increased exposure to noise, physical, mental and emotional health may be disturbed. People exposed to high levels of noise, compared to those less exposed, have an increased number of headache occurrences, higher sensitivity to small incidents, increased dependence on sedatives and sleeping pills, increased level of mental illness, etc. Exposure to noise is also associated with a number of possible physical effects such as colds, changes in blood pressure and other cardiovascular changes, problems with the digestive system, as well as chronic fatigue, while prolonged exposure to noise levels of 80 dB or more can cause deafness (Zatežić, et al., 2009). According to the World Health Organization, it is estimated that 1.3 billion people worldwide have hearing damage due to noise impact, while 10% of the world population is currently exposed to noise levels that can cause hearing damage (European Commission, 2015).

Intensive urbanization and industrialization in the modern world has contributed that noise becomes one of the most damaging environmental factors. At the beginning of this millennium, 50% of the planet's population is living in cities, and it is anticipated that this number will increase in 2025 to 75%. In 1960, there were only two cities in the world with over 10 million inhabitants, while in 2025 there is a prediction for 28 mega cities (Zatežić, et al., 2009). There is a trend of noise level increase in the underdeveloped part of the world and in developing countries where extremely high noise levels between 90-100 dB occur as a result of the dominant use of outdated engines, diesel vehicles and motorcycles. It is generally accepted that a noise level of 55 dB is considered disturbing, while a noise level of 65 dB is considered intolerable. In accordance with this classification, it is estimated that 30% of the EU population live in conditions of unacceptable noise levels, while about 170 million people live in so-called 'gray areas' with high noise levels during the day (Radosavljević, Vukadinović, 2014, pp.925-930).

Also, cardiovascular diseases such as high blood pressure, heart disease and stroke are associated with long-term exposure to noise. This is corroborated by the results of the published studies showing that an increase in traffic noise levels of 10 dB may increase the risk of high blood pressure or heart disease from 7 to 17% (European Commission, 2015). Exposure to noise from road, rail and air transport over a longer period may also affect children's learning and development. A study conducted in 89 schools in the vicinity of major airports in London, Amsterdam and Madrid, for children aged 9 to 10, showed that the traffic noise adversely affects the ability of learning as well as memory (European Commission, 2015).

In Europe, in recent years, more attention has been paid to the problem of external costs of noise. Costs of exposure to noise are mainly related to the decrease in house prices, reduced possibilities of land use, increased medical costs, costs of lost productivity in the workplace, etc. In Switzerland, for example, the external costs of transport due to noise have been estimated to around 1.5 billion euros, of which 81% are attributable to road traffic, 15 % to rail and 4% to air traffic (European Environment Agency, 2014). In Sweden, social annual costs caused by road traffic noise are estimated at over a billion Swedish krona, 908 million are the estimated costs due to rail traffic and 62 million krona due to air traffic (European Environment Agency, 2014).

In the modern world, transport has been identified as the main source of noise pollution. Of all modes of transport, road transport, with a share of about 65% in the total traffic noise pollution from transport (Vukasinovic, 2013), appears as a major polluter. It is estimated that in the EU about 125 million people are exposed to road traffic noise exceeding 55 dB (European Environment Agency, 2014). The main noise sources of this form of transport are noise from engines, noise generated from the friction of wheels over the road surface and the noise from exhaust systems (Figure 1). When observing road traffic, one of the most important factors that affect noise intensity is the speed of vehicles. At low speeds, the impact of the vehicle structure is more important for the level of noise than the interaction of vehicles and the road surface. At speeds above 30 kph for passenger cars and 40 kph for trucks, the impact of tires on the road surface becomes significant, while at speeds over 50 kph this influence becomes dominant (European Commission Working Group 5, 2002). From the above, it can certainly be concluded that the noise level increases with vehicle speed increase. For example, a car moving at 20 kph emits 55 dB of noise, one that is moving at 40 kph generates 65 dB, a speed of 80 kph generates noise of 75 dB, while a speed of 100 kph generates up to 80 dB (Figure 2). Some studies have shown that in urban areas, where speeds are from 30 to 50 kph, the noise from the operation of vehicle engines plays an important role, while on the highway, the above mentioned noise source can be ignored.

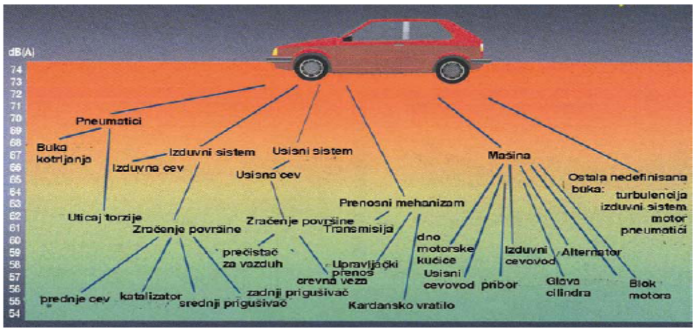

Figure 1 – Generation of noise by car
Рис. 1 – Генерирование дорожно-транспортного шума
Slika 1 – Generisanje buke koju emituje automobil

The intensity of the traffic noise of road vehicles depends on the "content" of traffic. So, for example, a truck at a speed of 90 kph emits noise intensity equal to 28 passenger cars which move at a speed of 90 kph (Bogojević, et al., 2011).

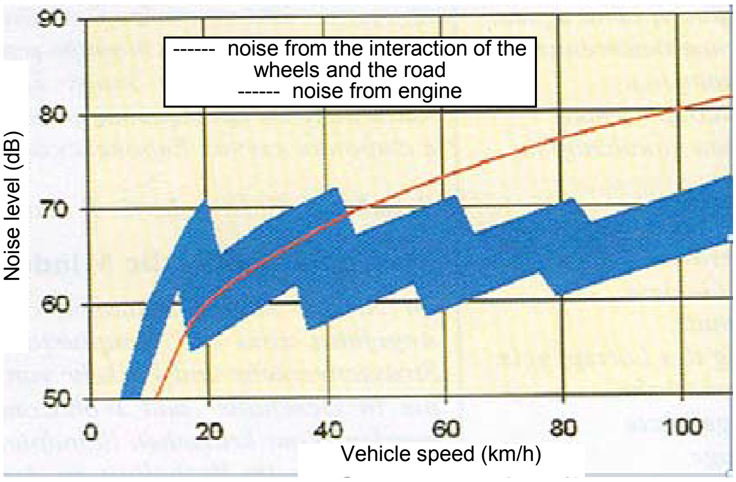

Figure 2 – The dependence of the noise level due to the interaction of tires and the road surface and due to vehicle engines
Рис. 2 – Зависимость уровня шума от контакта покрышек и поверхности дорожного покрытия, а также от работы двигателя
Slika 2 – Zavisnost nivoa buke od interakcije pneumatika i površine kolovoza i od rada motora vozila

The second largest source of noise emissions in transport is air transport in the total noise pollution from transport and it accounts for about 20% (Vukašinović, 2013). The problem of traffic noise in air transport has come to a focus due to the forecast that the volume of traffic in Europe by 2020 will increase by 3 times compared to 2000. Operations of landing and takeoff of aircraft (airplanes and helicopters) generate significant levels of noise near commercial and military airports. Noise caused by the operations of landing and take-off is directly dependent on the number of aircraft, landing and takeoff corridors and atmospheric conditions. Also, noise sources are aircraft propulsion systems and aerodynamic noise. Aerodynamic noise is dominant only in the phase of flight, whereas in the phase of landing and takeoff a dominant noise source is the propulsion system.

Rail transport accounts for about 15% of the total emissions in traffic noise (Vukašinović, 2013). The origin of this type of noise is linked to locomotives (mainly those that use diesel engines), friction between wheels and rails, locomotives and wagon braking, horns, crossing the railway crossings, aerodynamic noise produced when trains move at high speeds, and others. (Bogojević, et al., 2011). The noise emitted by locomotives mainly occurs during work of traction motors, engine cooling systems, gear systems and ventilation systems. The interaction of wheels and rails is a dominant noise source and directly depends on the speed and the geometric configuration of tracks. On straight track sections, noise is mainly generated as a result of surface roughness of wheels and rails, and their mutual friction, while at overcoming curves, wheels create more noise due to the sliding of metal wheels on rails. The cause for this phenomenon is of the constructive nature of wagons where wheels are fixed in parallel axes, thus taking the outer wheels more time to pass curves than the inner ones.

The noise generated by the braking process, in addition to the roughness of contact surfaces of wheels and rails, significantly depends on the type and kind of brakes used. So, for example, when braking with wheel slippers brakes with inserts made of cast iron, the noise level is 10 dB higher than in the case of disc brakes with discs mounted on wheels. In the case of wheels with slippers brakes with inserts of composite materials, the noise level is less than half the level of that of wheels with slippers brakes with inserts made of cast iron and disc brakes. The majority of fans and their motors generate noise. It is important to mention noise generated by sound signal alerts and notifications as well as aerodynamic noise caused by train running. The noise level generated by air turbulence is proportional to the speed of the train. Aerodynamic noise is significant only at higher speeds. Additional sources of noise in relation to rail transport are linked to the operations of loading, unloading and reloading.

The overview of the noise levels by types of specific means of transport is shown in Table 3, where it can be seen that combat aircraft and military vehicles emit the most noise (Zatežić, et al., 2009), (Živković, et al., 2000, pp.566-576).

Table 3 – Noise levels of means of transport
Таблица 3 – Уровень шума дорожно-транспортных средств
Tabela 3 – Nivo buke prevoznih sredstava

The means of transport	Exterior noise levels (dB)
Bus	72 - 75
Passenger car at a speed of 90 kph	82 – 87
wagon train	85 – 88
underground railway	98 – 103
truck	82 - 89
plane (passenger)	97 - 113
helicopter	89 - 110
a column of tanks	88 - 96

To estimate the costs caused by noise, it is necessary to solve first the problem of noise measuring, which arises from the same noise complexity as the external noise effects. In fact, one of the main characteristics of noise is reflected in its multiple behavior and the fact that noise changes in time and space. The difficulties in measuring noise are associated with the fact that the noise level depends on the characteristics of transport (vehicle types, traffic intensity, the behavior of drivers, etc.), on types, conditions and quality of roads and also on the characteristics of the environment. In the longer term, wind, weather and seasons also affect noise levels. This means that it cannot be determined with certainty what the noise level will be at a particular place at a particular time. However, if noise sources are defined appropriately, then it is possible with a certain degree of confidence to determine what the average noise level will be in the long term.

Reducing the impact of traffic noise

From the aspect of traffic external effects, transport policy is important as a whole, as a set of measures to guide the development and operation of traffic in desired frames. Specific measures which are of major importance in terms of ecology, in the case of traffic, refer to the standards to be observed by manufacturers of vehicles and parts, as well as those who invest or exploit transport infrastructure (rail, road infrastructure, airports, ports, etc.). In addition to technical innovations in engines, the application of quality energy sources, stringent emission controls, and stricter air quality standards, it is necessary to take measures to restrict car use and increase the use of mass transport of passengers (Službeni glasnik RS, 4/2008). As traffic volume and noise levels are closely linked, a further rise in the volume of traffic in cities can only continue to increase the level of noise. Reducing the use of private cars and increasing the use of public transport and the use of bicycles are some of the solutions to reduce the volume of traffic in residential areas, and therefore the noise it creates.

Activities to be implemented throughout Europe in order to reduce noise in the environment have a different priority compared to the environmental problems, often because it was thought that such issues are best handled at national or local levels. In the initial stages of the European Union, the regulation on noise management was based on the objectives of internal markets. As the information on the impact of noise on human health is increasingly becoming available, the need for a higher level of protection for citizens through a wider frame in the whole Europe is becoming more distinct. A milestone in the European strategy to combat noise was the adoption of the document "Green Paper" in 1996, which represents a new strategy to combat noise. Its vision for the year 2020 shows that no person should be exposed to noise levels which endanger health and quality of life, and that is necessary to avoid harmful effects of noise originating from all sources and to preserve quiet zones. The document "Green Paper" proposed a new framework for understanding the impact of noise and created opportunities for progress in three key areas:

- Raising the level of awareness about the impact of environmental noise,
- Better and more detailed public information and involvement of the public in solving the problem of noise, and
- Reducing noise levels as a part of an integrated strategy for better life on the Earth.

Also, the "Green paper" has defined the target values of noise reduction for four basic types of noise sources as well as the basic guidelines for achieving the set goals:

a) Reduction of road traffic noise emissions to 10 dB:

- noise reduction that occurs in the interaction of tires and the road surface in cooperation with constructors of tires and road linings,
- reduction of engine noise (machines, transmissions and exhaust systems) by using new materials and active systems to control noise and vibration,
- traffic management using modern systems which enable functioning of traffic without congestion and delays, and
- improving regulations.

b) The reduction of noise emissions of rail transport up to 20 dB for freight traffic and up to 5dB for fast tracks:

- reduction of noise generated by the interaction of wheels and rails using new materials for rails and wheels and new technology to connect rails,
- reduction of aerodynamic noise of trains for high-speed railways, and
- reduction of noise generated during braking and overcoming curves.

c) reduction of emissions of air traffic noise up to 10 dB per operation during landings or takeoffs:

- noise reduction at aircraft using new aircraft constructions with improved dynamics and active noise control measures, and
- optimization of landing and takeoff operations.

d) The reduction of noise emissions of equipment used outdoors to 10dB:

- identification of the parameters of certain categories of equipment that affect the generation of noise,
- correlation of noise emissions and the identified parameters, and
- monitoring the effects of individual and combined effects of noise sources on its perception.

On 25th June 2002, the European Parliament and the Council adopted Directive 2002/49/EC on the assessment and management of environmental noise, which is known as the "END". The Directive aims to define a general approach to avoid, prevent or reduce harmful effects stemming from exposure to noise and noise in the environment. In addition, the Directive aims at establishing a basis for developing EU measures to reduce noise emitted by the major sources, in particular road and rail vehicles and infrastructure, aircraft, external and industrial equipment and mobile machinery (Official Journal of the European Communities, 2002).

The activities regulated by Directive 2002/49/EC are:

- Monitoring the environmental problem: the competent authorities are obliged to draw up "strategic noise maps" for major roads, railways, airports and densely populated agglomerations.
- Informing and advising the public about noise exposure, its effects, and measures against noise.
- Addressing local issues related to noise by requiring the competent authorities to draw up action plans to reduce noise in problematic areas, as well as by maintaining the level of noise in the environment where it is at a satisfactory level.
- Developing a long-term strategy of the European Union, which includes targets for reducing the number of people vulnerable to longer-term noise levels and creating a framework for the development of existing policies on the reduction of noise at source.

There are four basic groups of measures to reduce noise levels from traffic:

- noise reduction at source,
- reducing the propagation of noise,
- noise protection at the place of immission, and
- economic measures and regulations.

The first group is a primary measure, while the other three are secondary measures of protection against noise. The paper will set out the measures considered for road and rail and trams.

Noise reduction at source

Road traffic

In road traffic, high noise levels arise as a result of the vehicle structure and the interaction between the vehicle and the road surface, so when talking about reducing noise at source, it is necessary to act on all these components. The operations relating to the improvement of the vehicle structure include a series of measures related to the reduction of noise originating from engines, transmission mechanisms of vehicles, tires and the like. In 1970, Directive 70/157/EEC was adopted about prescribed permissible motor vehicle (cars, trucks and buses) noise levels, and it has undergone several amendments until today. Vehicle production must meet the requirements prescribed in that Directive. Attention is increasingly focused on the possibility of reducing noise from the interaction between tires and the road surface, which can be achieved by:

- reducing the speed of vehicles,
- selection of a particular type of road track surfaces,
- maintenance of roads and vehicles,
- traffic management, and
- behavior of drivers and the introduction of restrictions.

Reducing speed. The noise level can be reduced by limiting the permitted speed of vehicles. This measure does not affect only the reduction of the noise level, but also affects the increase of security of traffic participants. Double reduction in vehicle speed can result in noise reduction from 6 to 8 dB (Figure 3).

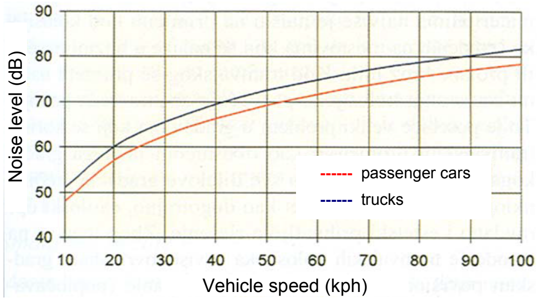

Figure 3 – Influence of vehicle speed on noise levels
Рис. 3 – Влияние скорости автомобиля на уровень шума
Slika 3 – Uticaj brzine vozila na nivo buke

Road surface. The road surface with an open and porous texture is not suitable only for noise reduction, it also provides a better tire grip and, consequently, better driving safety. Such a road surface reduces noise levels from 2 to 4 dB. The disadvantage of this solution lies in the need for intensive maintenance; in addition, considerable damage occurs during winter as a result of freezing.

Maintenance of roads and vehicles. Good maintenance reduces the dynamic effects of vehicles and load on the road, and affects the reduction of noise levels as well. Poor maintenance of roads greatly influences the increase of traffic noise, especially from the interaction of tires and the road surface (Lakušić, et al., 2005, pp.1-9).

Traffic management. Traffic management means the operation of reducing the traffic load by redirecting a part of the overall traffic or a certain type of vehicles to other roads, limiting the time in which it can operate (the ban on traffic of heavy vehicles during weekends and at night), and ensuring a status of free traffic flow (shutting down traffic lights). Free flow of traffic leads to noise reduction of up to 4 dB, while shutting down traffic lights can have a twofold effect – it cannot be better as it creates a possibility of increasing the speed of traffic, and the reduction of the noise level in this way is rarely higher than 2 dB. The effect of reducing the traffic load on the noise level is shown in Figure 4.

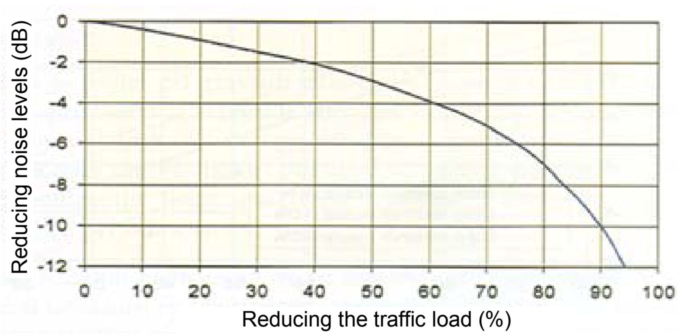

Figure 4 – Effect of reducing the traffic load on the noise level
Рис. 4 – Влияние снижения дорожно-транспортного движения на уровень шума
Slika 4 – Uticaj smanjenja saobraćajnog opterećenja na nivo buke

When speaking of diverting traffic, it should be noted that the removal of traffic from one road causes an increase in the noise level on other roads. This measure is somewhat justified if the traffic from smaller urban traffic is diverted to bypass roads or to those intended for intense traffic, which can result in a smaller increase in the noise level on the road to which traffic was diverted. For city roads, the mentioned measures can be significant.

Driver behavior and the introduction of certain restrictions. The noise level of an individual vehicle depends not only on its speed, but also on the degree of transmission and the methods of acceleration and deceleration. Passive driving can lead to reducing noise by approximately 5 dB for passenger and commercial vehicles, and by 7 dB for motorcycles (European Commission Working Group 5, 2002). Motorcycles are a particular problem because of a potential increase in noise up to 20 dB, and for this reason, driving bans can be introduced on certain roads at night or driving without a special built-in silencer can be prohibited.

One way of overcoming the problem of noise that occurs as a result of vehicle engines is the use of low-noise vehicles, such as hybrid vehicles, electric ones, etc. Hybrid vehicles are vehicles with low emission (LEV - Low Emission Vehicles), driven by two sources of energy: the energy conversion aggregate (combustion engine or fuel cell) and the aggregate for the accumulation of produced energy (Banković, 2010). Unlike hybrid vehicles, electric vehicles use exclusively electric motors as the main and only engines. The biggest car manufacturers are working intensively on the development of vehicles with hydrogen fuel cells. Hydrogen drive is particularly suitable for use in public transport vehicles. One of the advantages of fuel cell vehicles is that they are tanked much faster and that can cover more kilometers without refueling than electrically powered vehicles (Banković, 2010). Although beneficial, a silent operation of these vehicles can affect the safety of participants in traffic. Hybrid, electric and vehicles using hydrogen are particularly silent, to the point that they are silent even for pedestrians, which may affect their safety.

Railway and trams

The movement of railway vehicles, trains and trams, is also a significant source of noise. Today, rail transport is becoming increasingly important because freight traffic is trying to shift from road traffic to railways (European Commission, 2011). This leads to an increase in the volume of rail transport and the use of trains of considerable length. Without the application of protective measures, especially in those places where the railroad passes through populated areas, there would be a significant increase in noise levels. "European Commission Green Paper" of 1996 criticised rail transport for its contribution to the increase in noise levels and stressed that noise reduction is a prerequisite for its greater exploitation (European Commission, 1996). Reducing noise due to rail traffic can be accomplished by:

- selection of a type of construction of rail track superstructures,
- maintenance of the running surface of rails and wheels of vehicles,
- selection of a type of vehicles (wagons), and
- reducing the speed of trains and trams.

Type of construction of permanent tracks. The construction type of tram and railway superstructures plays a very important role in reducing noise emissions, especially types of rail mounting on the ground and a method of closing (covering) tracks. The choice of sleepers also affects the noise level. Research conducted in Germany has shown that the level of noise due to a train running on the track with wooden sleepers is up to 2 dB lower than in the case of the track with concrete sleepers. In addition to the system of fixing rails to their support, a method of closing (covering) the permanent track also has a very important role in reducing noise propagation. Closing a classical successive track structure with corresponding absorbent materials is mostly used for tracks on bridges located near settlements or passing through them. In tram transport, considerably more attention is devoted to a mode of closing tracks. This is a particularly big problem in cities that use tram transport as the main type of urban public transport. Therefore, setting up and closing tram tracks in urban areas create a major requirement in order to obtain the best possible construction of tram tracks which, in addition to aesthetic requirements, meet the requirement of reducing noise emissions.

The rail running surface. In Brussels in 2003, a working group of the European Commission dealing with noise from rail traffic formulated a strategy and priorities for reducing noise from rail transport. The greatest attention is given to noise due to the interaction of wheels and rails. The various geometrical irregularities both on wheels (flat points, irregularities in wheel shapes, mechanical damage) and rail running surfaces (wear, composition of rails, errors on welds) significantly affect the increase in noise levels. The Commission has adopted a strategy called 'smooth wheels on flat rails', in order to take stricter measures of control and maintenance of vehicle wheels and the running surface of rails. Of course, the development of modern and contemporary electromagnetic trains is one of the ways to reduce the noise impact of rail transport, since it allows movement of trains without wheels. They float on magnetic cushions without contact with the support; namely, they do not need wheels or cylinders, which means no friction and therefore no noise that occurs due to the interaction between wheels and rails. At a speed of around 200 kph, an electromagnetic hovering train is barely heard because its contactless technology does not produce neither noise nor the rolling noise of the engine. At higher speeds, the sound of aerodynamic wind can only be noticed; at a speed of 300 km/h electromagnetic trains are still quieter compared to a car moving at a speed of 70 kph and compared with a truck at a speed of 45 kph. However, one of the biggest disadvantages of this system is the high cost of construction. It is cost-effective only at railroad sections where large quantities of passengers and goods are transported.

Type of vehicles (wagons). A very important role in noise abatement is played not only by the type of construction of the tram track upper surface, but olso by the type of rail vehicles (wagons). Research conducted in the past has shown that different types of rail vehicles (tram, passenger or freight trains) have different effects on noise level increase. The construction of tram vehicles, stiffness and suspension characteristics of tram vehicle wheels in particular, contribute to reducing the level of noise emitted.

Reducing speed. Lower speed of rail vehicles contributes to the reduction of noise levels. At high speeds, a dominant noise source is the interaction of wheels and rails. At low speeds, noise levels are 3-7 dB lower than in the case of the train operating speed. Also, measurements of noise levels in urban areas have shown that at low speeds the tram noise level is lower by up to 10 dB.

Reducing noise propagation

As the reduction of noise levels at the source cannot often result in the prescribed permissible level of noise, noise reduction measures are applied involving the use of different barriers for protection against noise and planned utilization of space in the vicinity of motorways. It is known that roads and tram and railway roads generate high levels of noise in their environment. When the construction of new or reconstruction of existing roads is planned in populated areas, a special attention must be paid to the protection of existing facilities. In such cases, it is necessary to distinguish two situations: when the area near the road is less populated and when it is a densely built-up area. Proper planning of roads through sparsely populated areas can eliminate adverse effects of increased levels of traffic noise. In densely built-up areas, a careful attention must be paid to the protection of existing facilities. This includes urban planning of urban areas and roads in relation to buildings, planning and defining permissible noise levels for each zone, which can be regulated within the urban plans for settlements (Službeni glasnik RS, 88/2010).

In the process of planning and space management, in order to reduce noise propagation, it is possible to take the following measures:

- provide sufficient distance between residential areas and noise sources, and
- locate objects that are not affected significantly by noise (parking lots, shopping centers, etc.) in areas between noise sources and residential areas sensitive to high levels of noise.

The existing structures such as buildings, fences, billboards, tree lines, embankments, etc., located next to roads, are also a kind of barrier protection against noise even though it is not their primary function (Figure 5). In this way, in some cases noise levels can be reduced up to 12 dB (Lakušić, et al., 2005, pp.1-9).

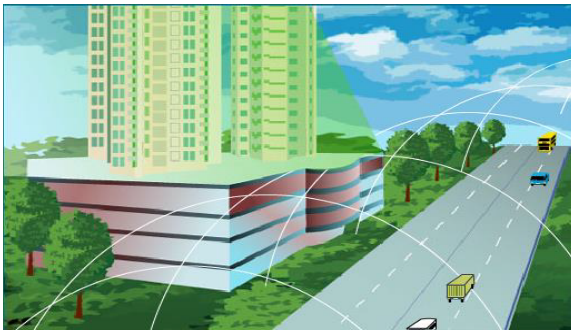

Figure 5 – Reducing traffic noise with objects
Рис. 5 – Снижение дорожно-транспортного шума с помощью объектов
Slika 5 – Smanjenje saobraćajne buke pomoću objekata

Setting up barriers for noise protection right next to routes (roads or railways) is one of the most common and safest ways to reduce noise propagation (Figure 6). For instance, Dutch national legislation in 1979 started solving this problem at a level a lot stricter than the regulations of the time. The result was the fact that in 2001 there were approximately 450 km of barriers for protection against noise positioned next to the national roads in the Netherlands, with the existing development plans to build additional 20 km every year. Barriers of sufficient height and sufficient length lead to the effect of reducing noise levels from 7 to 12 dB (European Commission, 2015). These technologies are not only economical, but can also be implemented in a relatively short period of time. Barriers for protection against noise fulfill their purpose by interrupting or blocking the direct path between the noise source and the receiver. Also, barriers may reflect noise, thus increasing noise for people living on the opposite side of the road. Therefore, a barrier against noise must have absorption characteristics.

Figure 6 – Barriers for protection against noise
Рис. 6 – Шумозащитный барьер
Slika 6 – Barijera za zaštitu od buke

Placing roads in recesses or constructing tunnels (when there is a need for a high degree of reduction of noise levels), are also methods of reducing traffic noise (Figure 7). Tunnels are built in urban areas where the price of land is very high and they are the most effective way of protection against noise. At the entrance, tunnel walls are usually lined with absorbent panels to reduce the propagation of noise in the environment. Wall cladding with panels is also widely used at the entrances and exits of underpasses which are more commonly used in urban areas. Namely, lining walls with absorbing panels can reduce noise levels by up to 10 dB (European Commission Working Group 5, 2002). However, this measure has its drawbacks which relate primarily to high construction costs as well as to significant costs of tunnel maintenance.

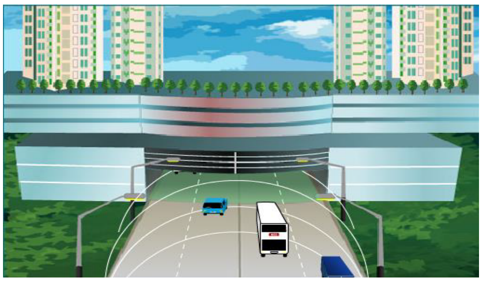

Figure 7 – Tunnels in the function of protection against traffic noise
Рис. 7 – Тоннели в качестве защиты от шума
Slika 7 – Tuneli u funkciji zaštite od saobraćajne buke

Protection against noise at the site of immission

If there is no possibility to reeduce noise at source or prevent its propagation, noise protection measures at the site of immission can be applied, reducing noise levels from 6 to 16 dB (Radosavljević, Vukadinović, 2014, pp.925-930). This method of noise protection involves the use of sound insulation, as well as greater attention to the design of buildings. When using acoustic insulation, the best effects are obtained by insulating walls, windows and doors. The use of sound insulation as well as noise protection is mainly considered as a last option because of the high cost. For example, the price of additional sound protection of a residential building is about 15% of the price of the object itself when the external noise level is 75-77 dB (European Commission Working Group 5, 2002). More and more attention is paid to the design of buildings. With objects placed along roads, the biggest problem with high levels of noise occurs in premises directly facing roads. To reduce the price of sound insulation in such a facility, at the design stage less sensitive areas (kitchen, bathroom, storage) can be oriented towards the road, so that the remaining parts (bedrooms, living rooms and study rooms) are on the 'quieter' side of the building.

Economic measures and regulations

Economic measures for the protection of the impact of traffic noise include fees for vehicles with noise levels higher than prescribed, incentives that support the reduction of noise level, fuel prices, establishing funds whose assets are intended for the implementation of measures for noise protection, research and development. Some of possible economic measures are:

- Incentives - for each dB below the permitted limit value, the manufacturer is provided a certain amount of money in the form of incentives, so that manufacturers can introduce their products to market at more competitive prices thus attracting more customers.
- Taxes - for each dB above the permitted threshold value, a vehicle owner pays a fee.
- Establishment of funds where money is collected by taxes, which can later be used for the implementation of measures for protection against noise or research and development of new technologies.
- Fuel prices can encourage customers to use quieter fuels (diesel engines produce more noise than gasoline ones), vehicles that consume less fuel (generally newer, better maintained and quieter vehicles), or to change their driving style (aggressive driving means that the engine rotates faster, which results in higher fuel consumption and increased noise levels).

However, even in developed countries, economic measures are not widely applied, although they represent an easier method of reducing noise levels. The reason for this can be found in the fact that such measures are difficult to control.

Situation in the Republic of Serbia

The issue of external effects of traffic and transport in the Republic of Serbia is extremely complex because of the country's unstable economic conditions, lack of funds, regulatory mechanisms, ecological culture and ethics. Despite the complexity of the problem, there are more reasons to pay attention to resolving these problems (Public Enterprise Roads of Serbiaa, 2012). Since external costs are difficult to define, quantify and charge through certain economic mechanisms, our theory and practice use European experiences which show that economic, environmental and transport policies are integrated to solve the problem of external costs of transport.

In the Republic of Serbia, traffic and transport are also the most prominent source of noise in the environment. More than 60% of the urban population in Serbia are exposed to traffic noise levels that are considered to seriously jeopardize the quality of life. Approximately 25%

of the population are exposed to such noise levels that have already caused health problems, which was confirmed by the Institute for Hygiene and Medical Ecology, Belgrade (izveštaj o realizaciji G2G projekta za Srbiju, 2011). Unlike in developed countries, in our country the concern about the problem of noise is still under-represented, often omitted. Health problems, whether they are of objective or subjective nature, reduced ability to work or even disability, are quite a sufficient reason for noise to be treated as an alarming problem of environmental pollution. Unfortunately, we must point out that in our country this danger is still not understood with sufficient seriousness, and is sometimes completely ignored. This is supported by the fact that, according to the report of the Agency for Environmental Protection, in 2012, out of the total investment in environmental protection, the percentage of funds allocated for programs of protection against noise was 0% (Agencija za zaštitu životne sredine, 2014). Measurements of noise levels have been carried out in Belgrade from 1970s (Gradski zavod za zaštitu zdravlja Beograd, 2002), (Izveštaj o realizaciji G2G projekta za Srbiju, 2011). Noise measurements in 2012 in Belgrade showed that the measured noise levels were higher than allowed during the day at 25 measuring points, while during the night higher levels occurred at 34 measuring points (Gradski zavod za javno zdravlje, 2013). Due to possible increase in traffic caused by the development and possible growth of economic activities, these numbers are expected to increase in the near future.

In 2013, the Institute of Public Health of Voivodina presented the Report on the assessment of the noise impact on the health of the population of Novi Sad within which citizens over 65 years of age were surveyed. Among other things, the report has shown that the most annoying is noise originating from transport (47%). Out of the total number of citizens surveyed, 46% would change a flat because of traffic noise, and 6% of them had already submitted a complaint to the authorities because of traffic noise. Also, more than a half of interviewed citizens (51%) said that they were awakened by traffic noise at night (Institut za javno zdravlje Vojvodine, 2013). The Institute for Material Testing, Belgrade, carried out noise measurements in the same city at seven locations in the period from June 2014 to May 2015. The analysis results showed numerous deviations of the measured noise levels from the presribed limits. This led to the conclusion that all measuring locations were critical, given that, in relation to the noise limit values, the deviations of the measured noise levels at all measuring points for the night were greater than 3 dB, while three measuring points were very critical given that their measured noise levels for day, evening and night were constantly higher than 10 dB (Institut za ispitivanje materijala a.d. 2015). Also, a 2014 study states that the levels of traffic noise for the city of Novi Sad in most cases are higher than 1 to 8 dB during the day, and from 1 to 9 dB during the night. Particularly worrying is the fact that the noise levels in school zones exceed the permissible noise levels for 12 to 16 dB, while in residential areas noise is higher from 9 to 16 dB during the day and from 11 to 18 dB during the night (Djercan, et al., 2014, pp.977-986).

According to the European Committee for Environment and Health, in Serbia there are difficulties associated with inadequate legislation and limit noise values, inadequate monitoring of noise in urban areas, lack of activity of noise zoning in the process of spatial planning, unfavorable locations of industrial areas, lack of projects for the protection of noise, insufficient monitoring of noise emitted by motor vehicles, as well as with inadequate traffic management (Izveštaj o realizaciji G2G projekta za Srbiju, 2011). There was also a lack of adequate knowledge about the development and application of low-noise road surfaces, which is why technology and knowledge related to the construction of this type of roads should be developed. The EU and worldwide experience should be used and modified to suit local conditions. Such an approach would create conditions for Serbia to apply low-noise road surfaces and barriers for protection against noise. In this way, the negative aspects of the impact of infrastructure development on the environment will be significantly reduced, and the noise levels will remain below the levels acceptable by the European Union standards and standards for environmental protection of the Republic of Serbia.

The situation in the Serbian Armed Forces

Military transport, as a part of the transport system of the country, also causes negative external effects of traffic and transportation. The noise of military vehicles is the result of a large number of devices and systems, each of which produces noise of more or less high intensity. The most significant sources of noise are: exhaust and intake systems, combustion noise and mechanical engine noise of military vehicles, cooling systems and tires, power systems and aerodynamic noise of military aircraft, moving of combat vehicles and others. Measures to reduce the noise external effects in the civilian sector can also be applied in the Army, especially in peacetime and in emergency conditions. However, research in the field of external effects of traffic caused by military vehicles is at the very beginning. But since these effects are more and more obvious, it is necessary to define at least the basic measures for minimizing external effects at this level of the development of the Army, such as:

- personnel training, analysis, public discussions, information,
- data monitoring,
- keeping a register of regulations and standards,
- limit exhaust gas emission,
- research and development of defense industry,
- acquisition of new and modern military vehicles,
- noise reduction, and
- resourcing and equipment in the function of traffic safety.

In the context of this task, it is necessary to raise the awareness related to the environment and development, which in the sphere of transport must be supported by concrete facts and arguments and presented appropriately. Similarly to former campaigns for traffic safety in the Army, it would be useful to focus more attention on the problems of traffic noise and possible directions for action and define complex programs to reduce the negative effects of the transport system at all levels in the Army.

Within the information system for monitoring the use of motor vehicles in the Ministry of Defense and the Serbian Armed Forces, it is necessary to make certain adjustments that would include the collection of data necessary for the analysis of noise. There is, however, a problem of purposefulness of the application of the appropriate methodology considering the existing structure of the Army's outdated vehicle fleet. Protective measures should follow from the knowledge about noise of traffic, in the campaign to raise awareness about the importance of protecting working and living environment. The application of new engines and better fuel emission control could improve the situation in the Armed Forces in the next decade. It is necessary to accept and try to apply the experience of other armed forces and adapt them to our conditions. Also, when carrying out peacetime tasks, the Army may be required to take into account the aspects of noise impact (use of means of transport which comply with the prescribed standards relating to noise).

Conclusion

The environment had long been considered a natural inexhaustible resource to which all lay claim. However, today's society faces the necessity to choose further steps to create conditions for the preservation of working and living environment. To this end, it is necessary to finally realize that all the nations are one family and one community on the Earth with the same destiny and that it is necessary to create a sustainable society based on the respect for nature and environmental ethics with built in responsibility for future generations. To achieve this goal, it is necessary that all people accept their share of responsibility for other people, for a greater community, and especially for future generations. In this context, environmental policy is not limited to the control of pollution at the local level, but it also has a global character.

Nowadays, noise and its harmful effects are on the increase. This is confirmed by the fact that damage to hearing by noise is among the most prominent health problems in the human environment, and if other effects of noise on the human organism are added, it is clear how serious possible consequences of noise pollution can be.Therefore, it is essential for science and practice to find mechanisms for controlling harmful effects of noise and measures against it, which will allow the smooth progress of people's business, social, recreational, creative and other activities.

A system approach to solving complex problems of adverse noise impacts of urban traffic systems has no alternative. In order to efficiently achieve tangible results in protection against noise, it is therefore necessary that all relevant factors, besides theoretical analyses, implement adequate measures to improve protection against noise impact, which would maintain and possibly improve the overall quality of the human life. Accordingly, measures such as reducing noise at source, setting up sound barriers, setting up green buffer zones in areas between roads and residential buildings, as well as adequate soundproofing of buildings, may contribute to a significant reduction of traffic noise adverse effects.

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НЕБЛАГОПРИЯТНОЕ ВОДЕЙСТВИЕ ШУМА, ПРОИЗВЕДЕННОГО ТРАНСПОРТНЫМИ СРЕДСТВАМИ

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ОБЛАСТЬ: логистика, транспорт
ВИД СТАТЬИ: профессиональная статья
ЯЗЫК СТАТЬИ: английский

Резюме:

В данной статье представлены основные понятия и характеристики неблагоприятных воздействий транспорта на окружающую среду, с акцентом на транспортный шум, который является главным негативным фактором транспорта в современном мире.

Приведены основные виды неблагоприятного воздействия транспортного шума на работоспособность и здоровье человека, а также причины возникновения высокого уровня шума, производимого автомобильным, железнодорожным и трамвайным транспортом.

В работе также приведен перечень стандартных мер защиты от воздействия шума, производимого транспортными средствами. А в заключении представлен краткий анализ данных воздействия транспортного шума на окружающую среду в Республике Сербия и Вооруженных Силах РС.

Ключевые слова: *транспорт, шум.*

BUKA KAO EKSTERNI EFEKAT SAOBRAĆAJA I TRANSPORTA

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OBLAST: logistika, saobraćaj
VRSTA ČLANKA: stručni članak
JEZIK ČLANKA: engleski

Sažetak:

U radu su prikazani osnovni pojmovi i karakteristike eksternih efekata saobraćaja i transporta, sa težištem na uticaju saobraćajne buke, kao jednom od glavnih eksternih efekata saobraćaja u društvu danas. Navedeni su osnovni negativni uticaji saobraćajne buke na čovekove životne i društvene aktivnosti, kao i uzroci nastajanja povišenih nivoa buke od drumskog, železničkog i tramvajskog saobraćaja. Takođe, navedene su uobičajene mere koje se mogu primeniti kako bi se smanjio uticaj buke koja nastaje kao posledica odvijanja saobraćajnih i transportnih aktivnosti. Na kraju, načinjen je i kraći osvrt na trenutno stanje po pitanju uticaja saobraćajne buke u Republici Srbiji i Vojsci Srbije.

Ključne reči: *saobraćaj, buka.*

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САВРЕМЕНО НАОРУЖАЊЕ И ВОЈНА ОПРЕМА
СОВРЕМЕННОЕ ВООРУЖЕНИЕ И ВОЕННОЕ ОБОРУДОВАНИЕ
MODERN WEAPONS AND MILITARY EQUIPMENT

Модернизовани индијски топ М 46[1]

Почиње „нови живот" за три топа М 46 који потичу још из времена Совјетског Савеза. Три топа М 46 130 мм модернизовани су тако што је извршена замена цеви са 130 мм на 155 мм/дужине 45 калибара, што представља стандард индијске војске. Завршена је техничка процена и од априла почињу тестирања.

Модернизовани топ М 46 130 мм

Индијска војска планира да модернизује 300 топова М 46 за суму од 153,84 милиона америчких долара. Топови ће бити распоређени у 16 пукова, што ће знатно повећати њихову ватрену моћ.

Компаније Punj Lloyd, Bharat Forge и Ordnance Factory Board извршиле су замену цеви, супресора на врху цеви и противтрзајног система топа М 46 ради коришћења граната 155 мм по НАТО стандарду. Једна од компанија, Punj Lloyd, сарађује са српском компанијом Југоимпорт СДПР у овом послу, док друга компанија, Bharat Forge, ради заједно са израелском компанијом Елбит. Трећа компанија, Ordnance Factory Board, већ је радила са израелском компанијом Soltam

[1] Jane's Defence Weekly 3 February 2016.

у послу модернизовања 180 топова М 46 на калибар 155/45 у програму који је завршен 2001. године и у којем је пренаоружано 10 артиљеријских пукова по цени од 45,52 милиона долара. Индијска копнена војска, у чијем је поседу око 300 система М 46, одредила је рок од 12 месеци компанијама учесницама програма за представљање платформе за техничку евалуацију.

Копнена војска планира да се тестирање модернизованих топова М 46 обави у периоду од пет месеци, што би значило да ће се до краја 2016. године знати ко ће бити успешан понуђач за програм модернизације у трајању од 60 месеци.

Компанија Punj Lloyd тренутно је у фази преговора са индијским министарством одбране за програм модернизације 428 противваздушних топова ZU-23 2 В. У оквиру модернизације овог противваздухопловног оруђа, механички нишански систем биће замењен електрооптичким компјутеризованим системом за управљање ватром, што ће омогућити да топ гађа циљеве на даљинама до 2.500 м и на висинама до 300 м, дању или ноћу, на различитим теренима.

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Вишеструке бојеве главе за DF-5A[2]

Кинеска народноослободилачка војска (КНВ) модернизује своје старије интерконтиненталне балистичке ракете на течно ракетно гориво Dong Feng-5A (DF-5A или CSS-4 Mod 2) модерним вишеструким бојевим главама са могућношћу независног гађања циљева.

Кинеске интерконтиненталне балистичке ракете DF-5B

[2]Jane’s Defence Weekly 17 February 2016.

САВРЕМЕНО НАОРУЖАЊЕ И ВОЈНА ОПРЕМА / СОВРЕМЕННОЕ ВООРУЖЕНИЕ И ВОЕННОЕ ОБОРУДОВАНИЕ / MODERN WEAPONS AND MILITARY EQUIPMENT, pp. 892–929

Током фебруара 2016. године процурела је информација да се једноструке бојеве главе ракете DF-5A замењују са по три независно вођене бојеве главе.

Систем независно вођених бојевих глава вероватно је исти као онај на ракети DF-5AB која је приказана на кинеској војној паради у септембру 2015. године. Претпоставља се да обе ракете, поред бојевих глава, носе топлотне и радарске мамце ради контрирања противничке против- ракетне одбране.

Током 2009. године процењивало се да Кина има „негде око 20” ракета CSS-4 Mod 2, али уколико је у току процес модернизације ракета DF-5A, могуће је да је ракета DF-5B потпуно нов тип који је тек у фази производње. У том контексту сасвим је могуће да је укупан број интерконтиненталних балистичких ракета DF-5 много већи него што се претпоставља.

Кинеска народноослободилачка војска је пред крајем развоја интерконтиненталних балистичких ракета DF- 41 на чврсто гориво, чији ће се лансери налазити на транспортним и шинским возилима.

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Озбиљна балистичка противбродска претња[3]

Развој и размештање мањег броја специјализованих оперативних противбродских балистичких ракета (ASBM Anti-ship ballistic missile – Противбродска балистичка ракета) модела под ознакама DF-21D (CSS-5) и DF-26 изазвала је велику пажњу у последње време.

Кинеска противбродска балистичка ракета DF-21D

[3] Jane's Navy International April 2016.

Кинеска балистичка ракета DF-26 са дометом до 4.000 км

Кина није прва држава која је инвестирала у програм ASBM. Раних седамдесетих година Совјетски Савез је покушао да пројектује први светски ASBM. Радило се о ракети R-27K (SS-NX-13) која је била предвиђена за лансирање са подморнице класе Project 629 „Golf".

Иако је Совјетски Савез располагао солидним бројем сателита за радарско осматрање океана, као и сателитима за његово електронско извиђање, овај нуклеарни ракетни систем имао је великих проблема са лоцирањем циљева и CEP (Circular error probability – вероватноћа циркуларне грешке) од чак 370 метара, што је било много чак и за нуклеарну бојеву главу. Овај ракетни систем никад није ушао у оперативну употребу.

Овај пример, са једне стране, приказује потешкоће које се појављују приликом развоја оперативног ASBM, али указују и на ограничења тадашње електронске индустрије која се, углавном, базирала на електронским цевима или првим генерацијама транзистора. Кина је усавршила технологију балистичких ракета и поседује много софистициранији сателитски систем него што је тада поседовао СССР.

Кинеска литература у вези са ASBM не бави се много совјетским напорима, нити указује на то да су та истраживања имала значајнију улогу у каснијем кинеском развоју ракета овог типа. То је мало неуобичајено за Кину која је одувек гледала на Русију као модел за развој својих оружаних система. У овом случају, Кина је обратила већу пажњу на САД и то у погледу развоја балистичке ракете Pershing II која је била снабдевена маневарабилним бојевим главама.

Када је 1983. године уведен у оперативну употребу, Pershing II била је прва балистичка ракета која је била опремљена технологијом за терминално навођење, укључујући подешавајућа контролна пераја у својим атмосферским улазним возилима (RV – Re-entry vehicle), што је утицало да CEP ове ракете буде до 37 метара. Кинески стручњаци проучавају развој ове ракете још од 1976. године и чини се да су директно применили неке од тих технологија.

Неки кинески државни извори експлицитно наводе да је програм Pershing II директно инспирисао развој кинеског ASBM-а до те мере да се тврди да је ракета DF-15/CSS-6 изграђена по основу ракете Pershing II. Неке верзије улазних возила ракета DF-15 имају и контролна пераја по узору на амерички модел.

A2/AD способност

Од средине деведесетих година Пекинг је развијао ASBM системе као део система A2/AD против приступа/ограничења зоне (A2/AD anti access/area denial). Систем је замишљен да држи непријатељске бродове под сталним ризиком разорних напада из разних праваца користећи балистичке и крстареће пројектиле са различитих копнених, ваздушних и поморских/подморничких платформи.

СврхаA2/AD јесте постизање контроле „блиских мора" (Жутог, Источнокинеског и Јужнокинеског мора). На тај начин кинески стратези замишљају експлоатацију кинеске стратешке дубине у смислу „коришћења копна за контролу мора".

На војној паради 2015. године у Пекингу приказано је скоро дванаест балистичких ракета, укључујући два кинеска ASBM система: DF-21D и DF-26 за које се сматра да су оперативни.

Званични коментатор параде назвао је DF-21D „мобилном противбродском балистичком ракетом" што потврђује и Пентагон, који наводи да је Кина увела у оперативну употребу ASBM са ракетама DF-21D којима је циљ да угрожавају непријатељеве носаче авиона на даљинама до 900 наутичких миља од кинеске обале. Затим се у истом извештају наводи да је DF-21D (CSS-5) противбродска балистичка ракета домета од 1.500 км, која поседује маневарабилна атмосферска улазна возила и омогућује кинеској народноослободилачкој војсци да напада бродове у западном делу Пацифика.

Пентагон је прве коментаре о балистичкој ракети великог домета DF-26 објавио још 2010. године и констатовао да се ради о ракети са могућношћу удара на копнене и поморске циљеве (бродове велике и средње тонаже) са средњих и великих даљина.

Током 2016. године званични кинески часописи објавили су да је извршено симулирано лансирање 10 ракета DF-21D у јужном делу Кине, без навођења детаља. Истраживачи су затим потврдили да DF-26 могу напасти у моменту када је доступна информација о положају брода, што указује на то да ракета поседује многобројне механизме „брзе замене" нуклеарних са конвенционалним бојевим главама, брзо премештање по копну, брзе припреме за лансирање и брзо премештање на друге положаје.

До овог тренутка не постоје званични извештаји о томе да је Кина спровела интегрисано тестирање својих ASBM система, али се интернетом шире приче да је спроведен тест гађања брода за подршку свемирским операцијама без званичне потврде. Све ове информације указују на то да су обе ракете у оперативном стању.

Са друге стране, није могуће сагледати способност кинеског осматрачког/ударног комплекса за прибављање тачних нишанских података за употребу ASBM система. Западни аналитичари долазе до закључка да Кина нема довољних обавештајних, контролних, осматрачких и комуникационих способности да би могла ефикасно употребити ракету DF-26 у нападу на бродове. Шпекулише се да би ракета могла бити употребљена на много краћим раздаљинама.

Основна компонента при употреби ASBM система су C4ISR (command, control, communications, computers, intelligence and reconnaissance – командне, контролне, комуникационе, рачунарске, обавештајне и осматрачке способности). То је неопходан предуслов за ефикасно ангажовање ASBM система. Успешно прибављање прецизних сателитских снимака у реалном времену и прибављање података о локацији циља, као и њихово неопходно умрежавање, представља основни предуслов за успешно лансирање.

Осматрачко-ударни комплекс ASBM подразумева увезане копнене радаре и сателите, као и употребу беспилотних летелица и микросателита.

Овај комплекс захтева прибављање информација са различитих извора, што је у пракси тешко изводљиво, јер једно је откривање и идентификација циља, док је сасвим друго праћење и прослеђивање таквих информација у реалном времену ASBM системима. Избегавање колатералне штете представља и додатно оптерећење.

Свемирско осматрање једна је од основних карика система. Кина је недавно лансирала различите сателите у великом броју. Без обзира на број сателита, ради се о комплексној надзорној архитектури чије компоненте контролишу различити оператори, а затим се поставља проблем фузије свих постојећих података с обзиром на различите типове сателита који се налазе у различитим орбитама и достављају различите врсте информација.

Кинески осматрачки сателити поседују елеткрооптичке сензоре. Постоје мулти и хиперспектралне варијанте, као и радарски сателити. Кина је лансирала укупно 39 сателита типа Yaogan-9 који могу пружити слике војних циљева у свим таласним дужинама и у средњим резолуцијама. Већина ових сателита налази се у орбити и у потпуности су функционални. Највећи део сателита чине сателити типа Yaogan-9, -16,-17,-20 и -25 A,B,C који у триангуларним конфигурацијама чине највећи део кинеског осматрачког система.

Сателити лете у триангуларним конфигурацијама од којих свака тројка садржи један сателит са електрооптичким сензорима – један за радарско осматрање и један за осматрање електронских емисија. Кинески извори наводе да су сателити намењени за лоцирање и праћење страних војних бродова и да обезбеђују тачне податке о њиховим позицијама које се шаљу ASBM системима. Претпоставља се да су ови сателити по својим карактеристикама слични првој и другој генерацији америчких сателита типа White Cloud Naval Ocean Surveillance System (NOSS) који пресрећу њихове електронске емисије и, у зависности од времена стизања сигнала, одређују њихову локацију.

Од поменутих типова сателита једино радарски сателити могу прикупљати релевантне нишанске податке с обзиром на то да не зависе од временских промена.

Поред сателита типа Yaogan, Кина је лансирала и следећу генерацију, типа Gaofen-1, -2, 4, -8 и -9, док се за типове -3, -5 и -6 очекује да ће бити лансирани током 2016. и 2017. године. Према поузданим изворима резолуција сателита типа Gaofen-1 је 2 метра у панхроматској резолуцији, 8 метара у мултиспектралној резолуцији и 16 метара у широкоугаоној мултиспектралној резолуцији. Резолуција сателита Gaofen-2 је 0,8 метара у панхроматској резолуцији и 3,2 метра у мултиспектралној. Сателит Gaofen-4 има камеру високе резолуције. Gaofen-8 се налази у нижој орбити ради снимања у већој резолуцији, док је Gaofen-9 предвиђен за замену сателита Gaofen-1. Сателит Gaofen-3 има синтетички радар резолуције од 1 метра, а Gaofen-5 снима у инфрацрвеном спектру. Gaofen-7 врши подметарско стерео мапирање. Кина је ове године лансирала 25 сателита типа Beidou/Compass, од којих је тренутно деветнаест оперативно. Очекује се да оствари циљ од 35 сателита који ће вршити глобално покривање до 2020. године.

Ради гађања мобилних поморских платформи, Кина мора савладати изузетно сложен и тежак процес корелације и фузије података добијених у реалном времену, а затим прослеђивање одговарајућих података у одговарајућем облику командантима и посадама ASBM система. Чак иако се постигне комплетно покривање релевантне поморске зоне, пренос података (од сателита до земаљских станица), тумачење података и, на крају, пренос података до ASBM система захтева много времена.

Упркос свим могућим ограничењима, Кина је постигла значајан прогрес и напорно ради на превазилажењу проблема. Она непрестано унапређује свој сателитски систем и лансира сателите темпом који прате само САД и Русија.

Кина је недавно инсталирала радарску инсталацију високе фреквенције на острву Cuarteron Reef који је у саставу Спретли острва. Овај радар има ефикасан домет до 370 км, па ће постављање више оваквих радара на овом архипелагу омогућити детекцију и извештавање о циљевима у Јужном кинеском мору.

Ирански ASBM систем

Кина поседује два функционална ASBM система, али и даље развија и унапређује осматрачко ударни комплекс који би омогућио ефикасно лансирање ракета у реалним и сложеним условима. Иран има сличне A2/AD аспирације у погледу Голфског залива, али много заостаје за Кином. Они фактори који представљају изазов Кини непремостиви су за Иран. Једини охрабрујући фактор за Иран јесте што он жели да контролише много мању површину од Кине.

Ирански ASBM систем Khalij Fars

Ирански ASBM систем Khalij Fars („Persian Gulf”) заснован је на серији балистичких ракета кратког домета Fateh-110. Ове ракете, с обзиром на управљачке површине, макар би у теорији могле да изврше довољне летне корекције ради удара на покретни поморски циљ.

Према наводима иранских званичника, основна одлика ракете је у њеној суперсоничној брзини и путањи. Друге ракете лете углавном субсоничном брзином, док Khalij Fars узлеће вертикално након лансирања, лети суперсоничном брзином, налази циљ путем софтвера, наводи се и удара у циљ. Домет ракете на чврсто гориво је 300 км и може бити лансирана из троструких лансера. Ракета може успешно погодити мобилну мету која је величине десетог дела носача авиона.

Изгледа да је ракета два пута тестирана, а оба теста спроведена су против стационарних мета, баржи или малих бродова. Све то треба узети са резервом с обзиром на то да Техеран често претерује када наводи војне способности својих оружаних система.

Са друге стране, Иран сигурно не поседује довољну осматрачку инфраструктуру која би му омогућила напад на покретну мету у реалним условима.

Потенцијалне контрамере

Америчка војска је врло озбиљно схватила кинеске напоре у развоју ASBM система. За сада је Кина прилично успешна. Њени програми балистичких ракета и одбране од балистичких ракета напредују.

Употреба разних мера које утичу на смањење радарских и комуникационих емисија, употреба мамаца и ометачких емитера, непредвидиви оперативни потези могу утицати на отежано гађање покретне поморске мете, нарочито на великим даљинама.

Мере активне одбране такође су проблематичне. Потребан је велики број ракетних пресретача за уништавање ASBM, а њихова цена такође је веома висока. Тренутно САД на Пацифичком океану немају велики број бродова који у свом наоружању имају ракетне пресретаче .

Сједињене Државе и савезници тренутно стављају тежиште на ометање неких од главних кинеских слабости, а то су везе у оквиру самог ланца ASBM система. Напори америчке морнарице у погледу збуњивања совјетског осматрачког система за време хладног рата могу послужити као основа за разбијање врло комплексног ланца функционисања овог система.

Закључак

Кина је светски лидер у развоју балистичких ракета, док САД води у развоју одбране од ових ракета. Такође, Кина је једина земља која данас поседује посвећени, функционални ASBM систем. Овакви системи дуго ће остати резервисани само за највеће војне силе. Мање државе моћи ће да развију само знатно слабије ASCM (Shore-based anti-ship cruise missiles – обалне противбродске крстареће ракете), што је знатно јефтинија и приступачнија варијанта угрожавања покретних поморских мета.

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Русија је представила нови SU-30 SME „Flanker”[4]

Руска компанија United Aircraft Corporation (UAC) представила је SU-30SME „Flanker”, експортну верзију ловца Sukhoi „Flanker” на овогодишњем сајму ваздухопловног наоружања у Сингапуру.

Ловац SU-30 SME

Двоседи ловац SU-30 SME је извозна варијанта авиона SU-30 SM која је недавно ушла у оперативну употребу у Русији и Казахстану (а преговара се и о извозу у Иран).

SU-30 SM је изведена варијанта ловца SU-30 MKI који је развијен за индијско ратно ваздухопловство. Ова летелица поседује унапређени радар, нове комуникационе системе, као и ново катапултирајуће седиште. Поред тога, конфигурација наоружања авиона прилагођена је руским спецификацијама, а француска опрема уграђена на SU-30 MKI замењена је руском.

С обзиром на то да ће ловац SU-30 SME имати исте, руске системе, као оне који се налазе на авиону SU-30 SM, није јасно колико ће се ова експортна верзија разликовати од верзије SU-30 MKI.

Совјетски Савез извозио је авионе својим савезницима, а они су углавном поседовали лошији радарски и оружани систем. У том контексту могуће је да ловац SU-30 SME буде опремљен мање модерним системима у односу на руску верзију SU-30 SM. Такав ловац могао би бити намењен оним државама које немају одговарајући буџет или техничко знање за употребу такве платформе, али је могуће да Москва одређеним државама не би ни дозволила употребу истог авиона као у својим оружаним снагама.

[4] Jane's Defence Weekly 24 February 2016.

Иако је ово најновија верзија SU-27, SU-30 SME није и најмодернија. Најмодернији ловац у руском наоружању је SU-35S „Flanker-E” који спада у генерацију летелица 4+++ која употребљава пету генерацију технологија. Русија је до сада добила 48 ових модерних летелица (управо је почела испорука следећих 50 комада) и с обзиром на кашњење у развоју ловца Sukhoi T-50 PAK FA, очекује се да ће они представљати окосницу руског ратног ваздухопловства у блиској будућности.

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Откривени нови детаљи у вези с тенком T-90 MS[5]

На тенку T-90 MS уведен је одређени број иновација и побољшања у односу на претходну извозну варијанту T-90 S.

Тенк T-90 MS

[5] Jane's International Defence Review January 2016.

САВРЕМЕНО НАОРУЖАЊЕ И ВОЈНА ОПРЕМА / СОВРЕМЕННОЕ ВООРУЖЕНИЕ И ВОЕННОЕ ОБОРУДОВАНИЕ / MODERN WEAPONS AND MILITARY EQUIPMENT, pp. 892–929

Инсталиран је најновији дизел-мотор В-92С2 са снагом од 1.130 КС, што је довело до повећања односа снаге и тежине. Нови мотор повезан је аутоматским мењачем, а додат је помоћни моторни агрегат.

Т-90 MS опремљен је најновијим топом 125 мм 2А46М-5 компаније Artillery Plant No 9 са глатком цеви за који се сматра да је прецизнији од претходних верзија 125 мм. Ова верзија основног тенковског топа опремљена је термалном облогом, екстрактором димних гасова и референтним системом на устима цеви.

Осим стандардних дводелних граната топ испаљује и ласерски вођене пројектиле до максималне даљине од 5.000 м. Ласерски вођени пројектил има високоексплозивну противтенковску тандем бојеву главу која може неутралисати циљеве опремљене експлозивно-реактивним оклопом.

Тенк је наоружан коаксијалним митраљезом 7.62 мм, док командир има на располагању даљински управљану оружну станицу са митраљезом 7.62 мм, док стандардни тенкови Т-90 и Т-90 S располажу митраљезима 12.7 мм.

Командиру је, такође, на располагању стабилизован панорамски осматрачки систем компаније Peleng JointStock који поседује телевизијски и термални канал, као и ласерски даљиномер.

Ова компанија нуди и термални систем са средњеталасним и дуготаласним ИЦ верзијама са ласерским даљинарима који раде на таласним дужинама од 1,06 или 1,54 микрона.

ТВ канал опремљен је широкопојасним и ускопојасним опцијама рада, док ова друга опција поседује и двоструко електронско увећање.

Ласерски даљинар има максимални домет до 7.500 м и тачност у распону од плус-минус 10 м.Осим што снабдева информацијама, компјутеризовани систем за управљање ватром, ласерски даљиномер такође омогућује лансирање ласерски вођеног пројектила у оквиру задатих граница.

Нишанџија има на располагању стабилизован нишански систем са телевизијским и термалним каналима, ласерски даљиномер, као и могућност вођења ласерски навођене ракете. Према наводима компаније, ови нишански системи омогућују тенку Т-90 MS да напада стационарне и покретне циљеве, док је сам тенк у покрету или у мировању. Системи, такође, обезбеђују и аутоматско праћење мете.

Труп и купола тенка Т-90 MS састављени су од завареног челика, ојачаног напредним оклопним пакетима. На предњем делу тенка налази се најновија генерација експлозивно-реактивног оклопа (ЕРА) који обезбеђује високу отпорност против кинетичких напада, као и против пројектила са експлозивним бојевима главама.

Задњи део тенка и куполе опремљен је решеткастим оклопом који обезбеђује заштиту од противтенковског наоружања, укључујући ракетне пројектиле.

Следећи ниво заштите долази од димне завесе која се добија убризгавањем дизел-горива у издувни систем. Возило је, такође, опремљено електрооптичким дефанзивним одбрамбеним системом који је повезан са избацивањем аеросолне експлозивне завесе. Ради се о систему такозване меке заштите (soft kill) за разлику од система тврде заштите (Hard kill) који је састављен од противракетних пресретача садржаних у систему нове генерације ARENA-E којим нови тенк за извозТ-90 MS ипак није опремљен.

Т-90 MS опремљен је и системом за управљање борбеним операцијама, као и копненим навигационим системом који су развијени у Русији.

Нови тенк приказан је потенцијалним купцима у Русији, али је приказан и у Кувајту.

Т-90 MS представља покушај даљег повећања експортног потенцијала серије Т-90, као и покушај што дужег одржавања производне линије.

Недостатак модерних осматрачких система одувек је била слаба страна руских тенкова и све до недавно то је било решавано увозом страних система. Међутим, изгледа да је Русија коначно превазишла овај проблем.

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Нови транспортер за руске ваздушнодесантне трупе BTR-MDM[6]

Руска компанија Kurganmashzavod започела је са производњом вишенаменског јуришног транспортера BTR-MDM намењеног за руске ваздушнодесантне јединице.

Транспортер BTR-MDM

[6]Jane's International Defence Review January 2016.

Ово возило представља дугорочну замену за старији BTR-D, оклопни транспортер трупа који се, као стандардно возило овог типа, налази у руским ваздушнодесантним трупама од 1974. године.

Као и возило DMD-4M, јуришно возило ваздушнодесантних снага, такође производ компаније Kurganmashzavod, BTR-MDM садржи велики број подсистема који се налазе у борбеном возилу пешадије BMP-3, као што су погонски агрегат, електрични систем и информациони управљачки систем.

Иако је BTR-MDM првенствено намењен употреби у ваздушнодесантним снагама, постоји могућност да га користе и руски маринци. Ово возило оформиће основу за породицу специјализованих возила, као што су амбулантна, командна и контролна возила, и разне логистичке варијанте.

Возило ће моћи да се користи и као платформа за превоз оружаних система, као што су тимови за противтенковске вођене ракете, тимови наоружани аутоматским бацачима ракета 30 мм AGS-17 или посаде минобацача од 82 мм и 120 мм. У овој улози возило би ипак морало бити ојачано ради компензације повратног дејства оруђа уколико би се разматрала идеја о испаљивању мина из самог возила.

Труп транспортера BTR-MDM израђен је од заварених челичних плоча које обезбеђују заштиту од ватре пешадијског наоружања и шрапнела распрскавајућих граната. Међутим, за разлику од возила BMD-4M, којем је додат додатни applique оклоп, а могуће је додати и експлозивно- реактивни оклоп, BTR-MDM нема, на први поглед, никакве везове на које би могао бити додат оклоп.

Уздигнут је простор за десантно одељење, али митраљез PKTM 7,62 мм није стабилизован

Возач се налази на средини предњег дела возила, а са сваке стране смештен је по један члан посаде. Члан посаде са десне стране возача рукује митраљезом PKTM који се налази на предњем крају возила. Митраљезом се нишани преко осматрачког система TNP3VE01-01 који је монтиран на крову. Иако је прегледност осматрачког система мала, ипак је могуће пружити ватрену подршку јуришном одељењу.

Члан посаде који седи са леве стране возача управља митраљезом PKTM 7,62 мм који је монтиран на крову, а нишани путем перископског дневног осматрачког система PPB-2. Митраљез је снабдевен са 2.000 метака.

Русија је развила један број стабилизованих даљински управљаних оружних станица које би могле бити уграђене на BTR-MDM ради повећања офанзивних способности возила.

Са обе стране трупа монтирани су редови стандардних руских бацача димних граната 81 мм, а као и већина руских возила вероватно је и да BTR-MDM има могућност стварања димне завесе убризгавањем дизел-горива у издувни систем.

Возило има капацитет примања 13 чланова десантног одељења који улазе путем кровних отвора или са задње стране возила.

Возило има компактан дизел-агрегат UTD-29T који развија 500 КС и упарен је хидромеханичком трансмисијом са четири брзине за ход унапред и једном за ход уназад. Моторни простор налази се испод задње стране возила, док су ваздушни усисници на горњој десној страни, као и четвртасти издувник.

Ранији модел BTR-D

Са масом од 13,2 тоне BTR-MDM има однос од 34 тоне по КС, што му омогућава знатну резерву снаге у случају неких будућих усавршавања.

Возило има подешавајући хидраулични амортизациони систем који може бити дигнут или спуштен, обезбеђујући максимални клиренс од 500 мм и минимални од 100 мм. У нормалним путним условима обично је подешен на 420 мм.

Као и BTR-D, BTR-MDM је у потпуности амфибијско возило и у води га покрећу две водене млазнице брзином до 10 км на час. Припрема за амфибијске операције своди се на укључивање пумпе и подизање препреке која се налази на предњој страни трупа.

Прва серија возила испоручена је Западном војном округу током марта 2015. године.

Русија је увек улагала знатна средства за своје ваздушнодесантне трупе, а након једног периода стагнације долази до испоруке нових система наоружања и опреме.

Као и ранији модел BTR-D и BTR-MDM има слабу оклопну заштиту и скучени простор за десантно одељење. Трупе немају седишта која ублажавају ефекат експлозије, иако то постаје стандард код борбених оклопних возила. Са друге стране, BTR-MDM се може спустити падобраном на место где га непријатељ неће очекивати и где може употребити своју маневарабилност за преживљавање и подршку другим оружним системима и платформама, као што су BMF-4M и 2S25 SPRUT са топом 125 мм. Очекује се појава нове генерације ових самоходних топова у виду 2S25 SPRUT SDM1 који се налазе у фази испитивања, а сматра се да ће бити произведени у већем броју примерака.

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Нова димензија поморске контроле групе носача авиона[7]

Систем NIFC-CA (Naval Integrated Fire Control-Counter Air – Поморски интегрисани систем за контролу ваздушног простора), пројектован за везу између ваздушних сензора и бродова у једну јединствену мрежу, завршио је тестирања у оквиру ударне групе америчких носача авиона.

Модерни бродови морали су да се суоче за закривљеном површином земље као природном препреком својих одбрамбених способности. Могућност откривања и ангажовања циљева простирала се онолико далеко колико су бродски и други сензори могле да „виде”. Како су потенцијални непријатељи напредовали у развитку својих могућности удара са великих даљина, напредовали су и системи забране приступа и развили се у много већи изазов за бродове који су, као резултат тога, морали да повећају зону откривања и деловања како би остали ван домашаја ракета.

Ради превазилажења ових изазова, САД су почеле да развијају нове могућности за ударне групе носача авиона, што би им омогућило да „виде” и нападну циљеве далеко ван линије хоризонта.

Концепт NIFC-CA је програм америчке ратне морнарице који је пројектован за проширење оружног система AEGIS путем умрежених сензора широм борбене зоне. Овај концепт омогућује ваздухопловним сензорима да пренесу нишанске податке назад ка оружном систему AEGIS који би затим одговорио на претњу лансирањем ракете SM-6.

Прва борбена група америчке ратне морнарице, која је испробала ову нову могућност, јесте група око носача авиона „Теодор Рузвелт ” (Theodore Roosevelt).

[7] Jane’s Navy International January-February 2016.

Носач авиона „Теодор Рузвелт”

Осмотрени циљ

Стандардни проблем свих војних снага је тешко пресретање циљева који лете на малим висинама. Од тренутка када је таква претња откривена, циљеви се већ налазе у оквиру линије хоризонта, па преостаје врло мало времена за одговор. У том контексту продужавање могућности дефанзивне детекције на великим даљинама, као и могућност захвата и напада мета на већим даљинама је оно на чему се ради већ две деценије.

Развој ове могућности започео је током 2004. године када је ратна морнарица тражила начин да пренесе тактичку слику ваздушне одбране преко шире интегрисане мреже платформи и система који укључују ловце и осматрачке авионе, бродске радаре и ракетне лансере. На основу концепта NIFC-CA, авиони би летели ван домета бродских сензора и проширивали слику интегрисаног борбеног простора изван линије хоризонта. Овај концепт, такође, омогућава гађање и употребу „паметних” оружних система и на тај начин повећава домет борбене групе без премештања средстава борбене групе у непријатељско окружење. Са развојем концепта и појавом нових технологија, поморски инжењери раде на томе да обезбеде потребан квалитет података добијен од ваздушних сензора који мора бити прецизан у мери да бродски оружани системи могу захватити и ангажовати потенцијалне циљеве.

NIFC-CA је омогућен путем постојања четири тактичка „стуба” који обезбеђују интегрисано управљање ватром противваздухопловних и противбродских оружних система: оружног система Lockheed Martin Aegis, ракетног система Raytheon SM-6, система Raytheon Co-operative Engagement Capability (CEC) и авиона Northrop Grumman E-2D Advanced Hawkey, ваздушног радарског система за ВОЈИН (ваздушно осматрање, јављање и навођење) опремљеног радаром AN/APY-9. Оружани систем Aegis се сада, на основу модернизације Baseline 9, појављује у три различита облика. Намењен је за употребу на крстарицама класе CG 47 Ticonderoga, на разарачима класе Arleigh Burke Flight I и II, као и копненом систему Aegis Baseline 9B који је сада у изградњи у Румунији, а предвиђено је његово инсталирање и у Пољској као делу европског ракетног штита.

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Лансирање противавионске ракете SM-6

Америчка ратна морнарица поседује 84 брода са системом AEGIS. Морнарица је у процесу модернизације површинске флоте и надограђује системе AEGIS који се налазе инсталирани на крстарицама и разарачима на ниво Baseline 9A i 9C. Ракетне крстарице класе Ticonderoga, бродови USS Normandy (CG 60), USS Chancellorville (CG 62), USS Princeton (CG 59) и USS Cape St George (CG 71) модернизују се на ниво Baseline 9A, док је других седам бродова, од крстарице USS Bunker Hill (CG 52), па до брода Philippine Sea (CG 58), на реду за модернизацију. Разарач класе DDG 51 USS Arleigh Burke је у поступку модернизације који треба да буде завршен до марта 2016. године, док су друга два разарача те класе већ модернизовани. Ови бродови биће опремљени оружним системом SM-6.

Разарач класе DDG 51 USS Arleigh Burke

Радар AN/APY-9 који се налази на авиону E-2D Advanced Hawkey опремљен је електронском/механичком скенирајућом решетком која може функционисати као примарни сензор за вођење противваздухопловних ракета SM-6, али може и наводити ракете ваздух-ваздух AIM-120 AMRAAM које лансира ловац F/A-18E/F Super Hornet и то путем мреже за размену података Link 16.

E-2D Advanced Hawkey

Бродска мрежа CEC (Co-operative Engagement Capability) преноси податке који су компатибилни систему за управљање ватром на бродове у саставу ударне групе.

Развој система NIFC-CA почео је 2010. године, а прва успешна демонстрација извршена је 2012. године. У оквиру демонстрације сензорски систем на балону употребљен је за пренос нишанских података интегрисаног система за управљање ватром до мреже CEC која је иницирала и лансирала ракету SM-6. То је био први пут да је ваздушни сензор који не припада поморским снагама био употребљен за ангажман циља ван линије хоризонта путем система Aegis.

Током априла 2013. године надоградња Baseline 9A инсталирана је на крстарицу Chancellorsville, прву крстарицу опремљену новим системом Aegis. Брод је спроводио први тест лансирања ракете путем нове надоградње Baseline 9A. Систем је детектовао, пратио и навео ракету SM-2 на беспилотну летелицу која је летела на средњим висинама.

У серији тестова, одржаних 2014. године, ракета SM-6 успешно је пресрела мету BQM-74 која се налазила на максималном домету ракете који је износио 370 км.

На мору

Током марта 2015. године борбена група носача авиона USS Theodore Roosvelt (CVN -71) са пратећим бродовима, Normandy, разарачима USS Winston S Churchill (DDG 81), USS Forrest Sherman (DDG 98) и USS Farragut (DDG 99) постала је прва борбена група која је оперативно развила систем NIFC-CA. Током обуке на новом систему имала је преко 200 симулованих захватања и пресретања циљева.

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Са дистанце

Иако E-2D представља центар система NIF-CA у погледу контроле ваздушног простора, то ни издалека није једини ваздухопловни сензор који омогућује рад концепта. Како током следећих година буду стизали ловци F-35 Lighning II Joint Strike Fighter (JSF), као и нове беспилотне летелице за подршку поморским операцијама, рашће и потенцијална количина информација.

Овај ловац биће једна од најважнијих карика у систему NIF-CA. С обзиром на његове електронске способности очекује се да ће F-35 дати огроман допринос у прикупљању и дељењу информација са другим летелицама и бродовима путем дата линка.

Подаци из авиона иду у крстарицу опремљену системом Aegis, тако да радарски систем брода има податке и пре него што се нађе на екрану противничких бродова или авиона.

Радијус ловца F-35 и његова смањена радарска видљивост омогућиће америчким бродовима да виде циљеве далеко ван линије хоризонта и смање време реаговања борбене групе. Међутим постоји и један проблем. Наиме, F-35 користи директни линк (Multifunction Advanced Datalink – MADL – вишенаменски напредни даталинк), систем дигиталних гласовних команди и мрежу података којом комуницира са другим ловцима F-35. Проблем је у томе што бродови опремљени системом NIFC-CA и Aegis немају MADL, нити су компатибилни са линком 16, специфичним за пренос података између летелица.

Могуће решење било би конфигурисање надоградње Baseline 9 која би читала MADL. Тада би било довољно проверити да ли подаци потичу од ловца F-35 и систем би га прихватио као једног од многих ваздухопловних сензора. Демонстрација интеграције података из F-35 предвиђена је за 2016. годину.

Закључак

Систем NIFC-CA представља одговор на појаву нових ракетних система великог домета (преко 400 км) и великих брзина (хиперсоничних). У условима постојања оваквих претњи степен угрожености група носача авиона постао је врло висок. Систем NIFC-CA омогућава да се сви подаци са већег броја ваздухопловних и других сензора слију у један систем који затим бира адекватан начин одговора, било летелицама, било новим ракетним системом SM-6.

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Руски модуларни оружни систем[8]

Руска индустрија развила је и тестирала нову даљински управљану оружну станицу (ДУОС) под ознаком 6S21.

ДУОС је модуларног дизајна и намењена је инсталацији у новим и постојећим оклопним борбеним возилима (ОБВ) ради повећања ватрене моћи.

[8] Jane’s International Defence Review February 2016.

Даљински управљана оружна станица 6S21 на возилу BTR-80

Развијене су четири конфигурације ДУОС. Све располажу електрооптичким/инфрацрвеним уређајима на левој страни система на којој се налази и ласерски даљиномер. Постоје две опције осматрачких уређаја САМ и САМ 1. Осматрачки уређај ознаке САМ располаже ТВ камером и ласерским даљиномером, док је САМ 1 опремљен ТВ/ИЦ камером и ласерским даљиномером. У опцији је и термална камера, што би омогућило ангажовање циљева у свим временским условима.

Осматрачки систем може бити монтиран хоризонтално или вертикално. У случају када је постављен вертикално, опремљен је ТВ камером са уским и широким видним пољем, док су ласерски даљинар и ИЦ камера постављени изнад. У оба случаја оптички уређаји су заштићени заштитним поклопцима када нису у употреби.

Основна верзија ДУОС наоружана је тешким митраљезом 14.5 мм KPVT, верзија 6S21 01 наоружана је митраљезом 12.7 мм Kord док су верзије 02 и 03 опремљене митраљезима 7.62 мм PKTM. Ове две верзије разликују се по количини укрцане муниције.

Иако ДУОС није опремљен системом стабилизације оруђа, то је могуће накнадно интегрисати, што би омогућило систему да гађа циљеве док је у покрету.

Све верзије опремљене су системом напињања оружја, а верзију 03 могуће је пунити изнутра, под оклопном заштитом. Систем 6S21 има електрични систем окретања куполе за пуних 360 степени и елевацијом оружја која се креће од –5 до 75 степени.

У случају монтирања система на BTR-80 оружни систем воде нишанџија или командир. Командир седи у предњем делу возила са десне стране, поред возача који поседује навигациони систем.

Нишанџија има свој дисплеј, са одговарајућим контролама, који укључује балистички компјутер са аутоматским прорачунавањем нишанских углова и корекција, а везан је за борбени информациони и контролни систем возила.

Контролне јединице обезбеђују контролу елевације и азимута, а присутни су и сензори који укључују бројач муниције, као и сензори угла елевације и азимута, док је све то везано електричним кабловима са митраљезом у ДУОС.

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Потреба за хиперсоничном брзином[9]

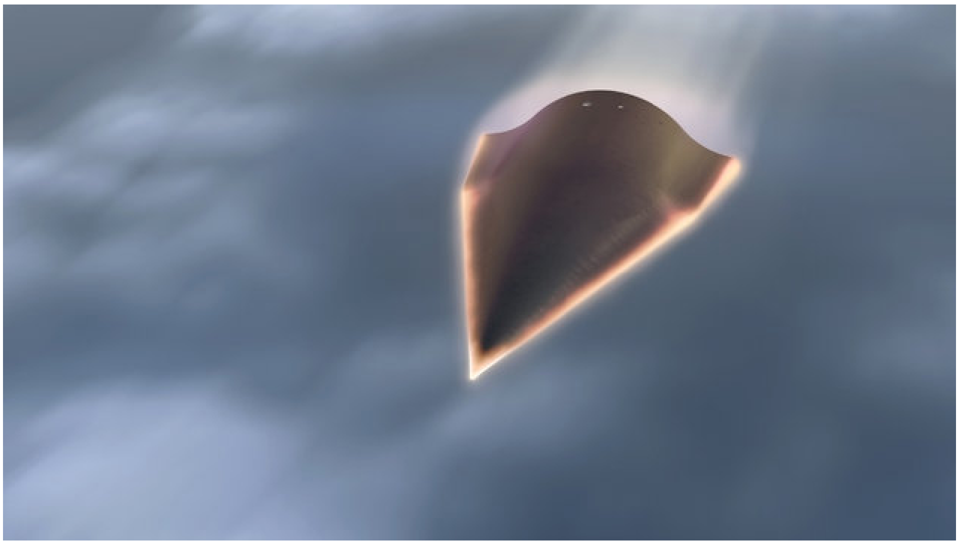
Америчко министарство одбране и друге америчке владине агенције развијају хиперсоничну технологију у правцу развоја хиперсоничног оружја и беспилотне летелице за надзор, које би могло бити оперативно до краја 2030. године, док се појава хиперсоничних свемирских возила очекује око 2050. године. И у овом случају развојна стратегија почиње са оружаним системима, па је тек након одређеног времена могуће развијати технологију за употребу у цивилне сврхе.

Америчко ратно ваздухопловство спровешће тест свог ударног оружја високих брзина (High Speed Strike Weapon – HSSW) након 2020. године. Тада ће се знати када ће нова технологија бити преточена у програм за набавку хиперсоничног пројектила. Демонстрација пројектила HSSW креће се у два смера. Први је програм компаније Lockheed Martin Raytheon, тактички ракетно планирајући пројектил (Tactical Boost-Glide– TBG), док други програм спроводи компанија Boeing, а ради се о концепту хиперсоничног оружја са усисавањем ваздуха (Hypersonic Air-breathing Weapon Concept – HAWC).

Одвајање хиперсоничног возила HSSW

[9] Jane's International Defence Review April 2016.

У оквиру ових програма ради се на истраживању нових материјала, нарочито композитних керамичких материјала који су и најважнији с обзиром на високе температуре са којима ће се суочити нове хиперсоничне летелице, као што су X-51 WaveRider и REACH.



Велике температуре на нападним деловима хиперсоничног возила HSSW

Демонстрација лета X-51 WaveRider представља основу планова америчког ратног ваздухопловства за развој наоружаних хиперсоничних летелица.

Приликом развоја летелице X-51 WaveRider, разне агенције већ су започеле рад на јачим моторима који би омогућавали брзине и 10 пута веће од брзине звука, што би било идеално за опремање платформи које би се бавиле обавештајним и надзорним пословима, али и за цивилне атмосферске крстарице. Већ сада се размишља о пројектовању мотора који би били стотинак пута бржи, а који би омогућили летелицама и пут у свемир.

Током маја 2013. године X-51 WaveRider је имао успешан лет. Летелица је откачена са бомбардера B-52H и достигла је брзину од 4,8 маха помоћу бустер ракете. Тада се одвојила од бустер ракете и укључила свој мотор. X-51 WaveRider је затим убрзао на брзину од 5,1 маха и летео следећих 210 секунди док није потрошио гориво.

Током претходних година компанија Lockheed Martin је сарађивала са америчком агенцијом DARPA на развоју концепта Falcon Hypersonic Technology Vehicle-2. За убрзавање летелице коришћена је ракета бустер, типа Minotaur IV, па су током 2010. године прикупљани подаци у вези с аеродинамиком, материјалима отпорним на високе температуре, системима за термичку заштиту, аутономним безбедносним летним системима и напредним навођењем, као и системима за контролу хиперсоничног лета.

САВРЕМЕНО НАОРУЖАЊЕ И ВОЈНА ОПРЕМА / СОВРЕМЕННОЕ ВООРУЖЕНИЕ И ВОЕННОЕ ОБОРУДОВАНИЕ / MODERN WEAPONS AND MILITARY EQUIPMENT, pp. 892–929

X-51 WaveRider на бомбардеру B-52

Два демонстрациона лета одржана су током 2010. и 2011. године, али оба пута је изгубљен контакт са летелицама типа Falcon.

Тренутно се резултати програма X-51 убацују у програм HSSW, док се развијају системи вођења преко два демонстрациона програма: HAWK и TBG. Агенција DARPA доделила је уговоре компанијама Raytheon и Lockheed Martin за наставак развоја програма TBG, док компанија Boeing у међувремену наставља са развојем програма HAWC. Циљ оба програма је достизање брзине од 5 маха и веће, с тим што се од оба оружана система очекује да буду отпорни на топлоту и маневарабилни. Такође, оружани системи требало би да досегну висину од око 60 км, док би бојева глава хиперсоничног пројектила била у рангу класе од 250 фунти, као бомба малог пречника (Small Diameter Bomb SDB).

Док је X-51 успешно демонстрирао интеграцију ваздушног возила и хиперсоничног погонског система, фокус пројеката HAWK и TBG биће на напредном систему навођења и контроле, што до сада није истраживано у прећашњим пројектима. Пројекат TBG покушава да развије технологије које би користио систем ваздушно лансиране летелице са тактичким дометом која би била ефикасна у релевантним оперативним условима и која би се, након достизања максималне брзине путем ракетног бустера, одвојила од бустера и прешла у планирање брзинама већим од 10 маха.

Са друге стране, пројекат HAWK, наставак програма X-51, настоји да демонстрира рад хиперсоничне крстареће ракете коју покреће скрамџет мотор на нешто мањим брзинама, око 5 маха или мало изнад. Ова технологија могла би да утиче на развој будућих вишекратних хиперсоничних ваздушних платформи које би се касније могле користити у развоју цивилних и свемирских летелица.

Иако је основни циљ агенције DARPA развој оружаних хиперсоничних летелица, током 2013. године започет је развој вишекратног невођеног ракетног бустера који би могао понети сателите мање носивости, од 1.360 до 2.270 кг у нижу Земљину орбиту, а истовремено би служио као тест возило за испитивање хиперсоничних брзина. Ради се о летелици XS-1 Experimental Spaceplane коју развијају компаније Northrop Grumman, Scaled Composites и Virgin Galactic. Очекује се да ће летелица моћи да носи терете по цени десет пута мањој од цене употребе данашњих ракета носача, а истовремено ће помоћи развоју нових хиперсоничних летелица. Ова летелица достизала би брзине веће од 10 маха, али слетала као авион на стандардним аеродромима, што би захтевало минималну посаду и инфраструктуру. Први орбитални тест планиран је за 2018. годину.

Овај пробој начињен је захваљујући појави нових лаких напредних композитних материјала велике термичке заштите који нису постојали осамдесетих година када су вршени први тестови са летелицама овог типа.

Свемирска летелица XS-1, компаније Northrop Grumman

Летелица XS-1 представља напор Пентагона за умањење трошкова лансирања сателита. Употреба тешких ракета носача је врло скупа и захтева пажљиво планирање. Ови традиционални лансери коштају по неколико стотина милиона долара и захтевају постојање сложене инфраструктуре. Ситуацију додатно компликује то што америчко ратно ваздухопловство ради на томе да стопира употребу руских тешких ракетних мотора типа RD-180, који се тренутно користе за лансирање сателита који су најосетљивији за америчку одбрану.

Русија надокнађује пропуштено

Пред крај постојања Совјетског Савеза, компанија Raduga израдила је хиперсонично експериментално летеће возило GELA (Giperzvukovy Ekspreimentalnyi Letatelnyi Apparat) које је практично било прототип стратешког пројектила Kh-90 (izdeliye 40) који је покретао рамџет мотор TMKB Soyuz izdeliye 58 и омогућавао му брзину од 4,5 маха на даљинама од 3.000 км. Било је предвиђено да стратешки бомбардер Tu-160M носи две ракете Kh-90. Рад на тим ракетама суспендован је 1992. године, док је GELA летелица приказана 1995. године.

Током 2013. године Русија је објавила да ради на програму развоја хиперсоничног пројектила. Први део програма предвиђа развој ракете подстратешког нивоа, домета до 1.500 км и брзине од око 6 маха и то до 2020. године. Овом програму следио би развој оружја брзине 12 маха који би покривао целу планету.

Када је у питању ракета брзине 6 маха вероватно је да се ради о пројектилу Izdelye 75 GZUR (Giper-Zvukovaya Upravlaemaya Raketa – хиперсонична вођена ракета) који је у фази техничког пројектовања у компанији Tactical Missiles Corporation team. Очекује се да ће пројектил Izdelye 75 бити дужине 6 м, што је максимум складишног простора бомбардера Tu-95MS, а величина одговара и бомбардеру Tu-22M. Ракета је тешка око 1.500 кг, покреће је рамџет izdeliye 70 компаније TMKB Soyuz. Активни радарски трагач под називом Gran-75 развија компанија UPKB, док пасивни трагач развија компанија Detal TSKBA из Омска.

Током 2012. године Русија је започела са тестирањем експерименталног хиперсоничног пројектила који је носио бомбардер Tupolev Tu-22M3 Backfire. Године 2013. ово возило је први пут самостално летело. Хиперсонично тест-возило било је смештено у предњем делу ракете Kh-22 (AS-4 Kitchen) који му је служио као ракетни бустер. Ова комбинација ракете бустера и возила дуга је 12 м и тежи око 6 тона, а хиперсонични елемент је дужине око 5 м. Компанија DMZ је 2012. године израдила 4 ракете Kh-22 (без трагача и бојеве главе) које су планиране за употребу у хиперсоничним пројектилима. Ракета је лансирана са бомбардера Tu-22M3 са брзине од 1,7 маха и висине од 14 км, па је тест-возило достигло максималну брзину од 6,3 маха на висини од 29,557 м пре него што је лансирано тест-возило које је достигло брзину од 8 маха.

Очекивало се да ће Русија учествовати у сличним тестовима лансирања француског хиперсоничног возила MBDA LEA са бомбардера Backfire, али нема података да је такво лансирање и извршено.

Током октобра и новембра 2012. године Русија и Индија су направиле прелиминарни договор у вези с радом на хиперсоничној ракети BrahMos-II.

Индијски програм развоја ракете BrahMos започео је 1998. године, након споразума о заједничком развоју са Русијом. На основу тог споразума главни партнери биле су руске компаније NPO Mashinotroyeniya и индијска компанија Defence Research and Development Organisation – DRDO.

Прва варијанта – суперсонична, радарски вођена крстарећа ракета, двостепеног је дизајна и употребљава чврсто ракетно гориво које убрзава ракету до суперсоничних брзина, док други степен употребљава рамџет са течним ракетним горивом који погони ракету брзином до 2,8 маха. Ту се, практично, ради о индијској варијанти руске ракете Yakhont.

Ракета BrahMos већ је испоручена индијском ратном ваздухопловству, копненој војсци и морнарици, а одлука о развоју хиперсоничне верзије ракете донета је 2009. године, као заједнички подухват првобитних пословних партнера.

Руско-индијски пројекат BrahMos-II

BrahMos-II (Kalam) развијена је ради достизања брзина преко 6 маха и постизања веће прецизности од првобитног модела. Ракета ће имати максимални домет од 290 км који је иначе лимитиран споразумом о режиму контроле ракетне технологије чији је потписник Русија и којим се забрањује развој ракета домета већег од 300 км за државе партнере. Ради постизања већих брзина, ракета BrahMos-II ће користити скрамџет мотор, а према неким извештајима руска индустрија већ развија одговарајућу формулу за ракетно гориво.

Кључна одлука приликом пројектовања ракете BrahMos-II јесте одржавање физичких параметара претходне варијанте, што би омогућило новој ракети да користи постојеће лансере и инфраструктуру.

Нова варијанта ракете предвиђена је и за напад на учвршћене објекте као што су подземни бункери и складишта наоружања.

Модел ракете BrahMos-II приказан је на сајму ваздухопловне опреме у Индији током 2013. године, а тестирање прототипа очекује се током 2017, док би финализована верзија била доступна 2022. године.

Један од основних идентификованих проблема ракете BrahMos-II управо је висока температура која се формира приликом хиперсоничног лета, као и налажење одговарајућих материјала помоћу којих би ракета била израђена.

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Закључак

Као прва економска и војна сила, САД воде истраживања у сфери хиперсоничних брзина, док се друге земље, као што су Русија и Индија, труде да не заостану.

Хиперсонично оружје било би врло тешко за пресретање и омогућило би ударе на већим удаљеностима и за краће време у односу на садашња ракетна оружја.

Ова оружја користила би се за удар на мете у тешко брањеним подручјима у којима би класичне ракете тешко пролазиле.

Пентагон је добио налог да пожури са развојем хиперсоничне технологије с обзиром на развој у Кини, Русији, па чак и у Индији.

Амерички званичници предвидели су да би вишекратна хиперсонична летелица могла бити оперативна до 2040. године, што је изузетно важно за САД, нарочито с обзиром на развој ситуације на Пацифику и јачање Кине као нове војне силе.

Америка је тренутно у предности у односу на своје потенцијалне противнике. Русија, Кина и Индија развијају само хиперсоничну ракету, док САД развијају вишекратну хиперсоничну летелицу, али и хиперсоничне ракете.

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Модернизовани Mi-8 MSB-V[10]

Украјинска компанија Motor Sich нуди велики број измена за украјински војни вишенаменски средњи хеликоптер Mi-8 MSB-V које су највећим делом намењене за одбрану од противваздухопловног оружја проруских снага из региона Доњецка.

Хеликоптер Mi-8 MSB-V

[10] Jane's International Defence Review May 2016.

Компанија нуди побољшања у смислу повећане ватрене моћи и преживљавања основне верзије хеликоптера Mi-8 MSB-V који користи војна авијација и национална гарда Украјине. Модификације се састоје од инсталације дигиталног система контроле наоружања Adron SKZ-8V и читаве палете нових убојних средстава ваздух-земља, као што су GKKB Luch Baryer-V и руски Sthurm-V (који потиче са хеликоптера Mi-24).

Ради постизања бољег преживљавања на бојишту, хеликоптер ће имати додатну оклопну заштиту кабине и систем за супресију инфрацрвеног зрачења Adron Adros ASH-01V који ће бити инсталиран на крајевима издувног система.

Компанија развија три варијанте Mi-8 MSB-V, под ознакама V-1, V-2 и V-3. Mi-8 MSB-V биће истовремено јуришни и нападачки хеликоптер. Навигационе системе опрема компанија Orizon Navigatsiya, белоруску електрооптичку куполу Tsiklon Bel, уређаје за ласерско упозоравање GKKB Luch, а радар и противавионске ракете, као и подвесне ракетне бацаче, компанија Adron.

Mi-8 MSB-V2 намењен је за улоге патролног и извиђачког хеликоптера који је сличан верзији V-1, али без противтенковских ракета. Уместо тога, ова верзија ће, на подвесним носачима, носити мале беспилотне летелице и одговарајући контролни систем.

За разлику од њега, Mi-8 MSB-V3 је предвиђен као ваздушно-командна и контролна платформа опремљена великим бројем комуникационих и информационих система са додатном оклопном заштитом на делу путничке кабине.

Mi-8 MSB-V је војна верзија цивилног и транспортног хеликоптера Mi-8 T и опремљен је новим и ефикаснијим моторима TV3-117VMA-SBM1V-4E, новим средствима за самоодбрану и могућношћу ношења оружја.

Компанија је током 2014. године добила први уговор за конвертовање 13 хеликоптера Mi-8 T на стандард MSB-V, од којих три иду националној гарди, а 10 војсци. Испоруке су завршене до краја 2015. године.

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Давидова праћка је оперативна[11]

Након завршетка финалне фазе развоја и успешних тестирања које су водили Министарство одбране Израела и америчко министарство одбране, компанија Rafael Advanced Defence Systems започела је са испорукама кључних делова система David Sling Weapon System DSWS (оружани систем Давидова праћка) израелском ратном ваздухопловству и команди ваздушне одбране.

Четврти тест Давидове праћке спроведен је на полигону у јужном Израелу и представљао је финални корак пре испоруке оперативног система израелском ратном ваздухопловству. Очекује се да сви елементи система буду комплетирани до половине 2016. године.

[11] Jane’s International Defence Review May 2016.

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Испорука DSWS првобитно је била предвиђена за 2015. годину, али је била одложена због низа техничких проблема и изазова карактеристичних за увођење нових система и технологија. Многи елементи система су потпуно нови, али је откривен и одређени број софтверских проблема који су решени.

Тестови су успешно завршени и систем је спреман за испоруку. Први елементи који ће бити испоручени укључују радар са електронском фазираном решетком, Elta ELM-2084 Mobile S-Band 3-D Active Electronically Scanned Array (AESA) мулти мисијски радар, Multi Mission Radar (MMR), центар за управљање битком, Elisra Golden Almond Battle Management Centre, комуникационо чвориште компаније Rafael, двостепени пресретач Stunner и лансер ракета који представља заједнички рад израелске компаније Rafael и америчке Raytheon. Испоруке компонената биће праћене тестирањем делова система, што ће претходити званичном увођењу у оперативну употребу. Компанија Rafael започиње са обуком првих оператера система Давидова праћка. Није наведен број подсистема DSWS који је испоручен израелском ратном ваздухопловству.

Пресретачи Stunner биће модернизовани на ниво Блок 3 (алгоритми и софтвер), док је тренутно у току развијање нивоа Блок 1. Блок 3 ће омогућити систему способност борбе са антиципираним будућим претњама.

Пресретач Stunner је двостепена ракета са вишепулсним ракетним мотором. Прва два пулса доводе ракету до половине домета до циља, а трећи пулс је активиран у тренутку када је одређен пресретачки курс и служи за убрзавање ракете ради повећања кинетичког удара по циљу. Компанија Raytheon испоручила је бустер ракете, навигациони систем и електронику за навођење, док је компанија Rafael испоручила ракетни мотор, склоп за навођење и контролни софтвер и радар са електрооптичким трагачем (који је развила компанија Israel Aerospace Industries). Интеграцију свих подсистема пројектила Stunner извршила је компанија Rafael у Израелу.

DSWS је заједнички програм који су финансирали израелска организација за ракетну одбрану и америчка агенција за одбрану од ракета. Ради се о противракетном систему средњег домета за пресретање тактичких балистичких ракета, ракета средњег до дугог домета, авиона, као и крстарећих пројектила у ниском лету који су лансирани са даљина од 70 до 300 км. DSWS је предвиђен да попуни празнину између израелског система двоструке намене Iron Dome за пресретање ракета, као и артиљеријских зрна и минобацачких мина и система Arrow Weapon System, система за одбрану од балистичких ракета који су већ у оперативној употреби у оквиру израелског ратног ваздухопловства.

DSWS неће бити употребљен као „батерија”, јер дефиниција батерија није употребљива у овом контексту. Један систем не може бранити цео Израел. То је зонски систем, део израелског система противваздухопловне одбране. Са минималним бројем подсистема, као што су сензори, лансери и комуникационе станице, систем може штитити цео Израел. Ради се о систему који чини део израелске вишеслојне противваздухопловне одбране.

Концепт вишеслојног система развијен је 2001. године и тада је био састављен од два слоја, а сада се говори о четири слоја, Iron Dome, David Sling, Arrow 2 , а на крају и Arrow 3. Овде се ради само о израелским системима. Када се додају и амерички системи, као што су Aegis Weapon System, Standard

Missile 3 Terminal и High Altitude Area Defence (THAAD), долази до знатног повећања ефикасности укупне одбране од претње балистичким ракетама.

Компаније Rafael и Raytheon заједнички раде на развоју ракете Stunner као јефтиније алтернативе америчком систему Patriot. Систем Patriot Advanced Affordable Capability 4 (PAAC 4) није нов систем већ представља интеграцију ракете Stunner у систем Patriot, што би омогућило инкорпорацију и продају те ракете у оквиру постојећих система Patriot. Ракета Stunner представља концепт отворене архитектуре и може бити интегрисана у различите системе противваздухопловне одбране.

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Нови севернокорејски ракетни мотор[12]

Северна Кореја тестирала је нови ракетни мотор на течно ракетно гориво за своје интерконтиненталне балистичке ракете.

Севернокорејски званичници изјавили су да ће сада бити у могућности да ставе много моћнију нуклеарну бојеву главу на нову интерконтиненталну балистичку ракету која ће покривати део САД.

На сликама је могуће видети да нови мотор користи две главне потисне коморе и још четири потисника типа Vernier који служе за управљање ракетом. На делу снимка мотора интерконтиненталне балистичке ракете KN-08 виде се, такође, две главне потисне коморе и четири потисника типа Vernier.

Нови ракетни мотор на течно гориво за ракете KN-08 KN-14

[12] Jane's Defence Weekly 20 April 2016.

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Фотографије које датирају од 6. марта и 9. априла показују да се главне потисне коморе налазе у резервоарима за гориво. То је иновација руске компаније Isayev Bureau која је употребљена на мотору 4D10 који погони подморничку балистичку ракету R-27.

Постоје индиције да је Северна Кореја добила неке од ових балистичких ракета из нуклеарне балистичке подморнице Project 629 „Golf" коју је деведесетих година Русија одредила за расход и продала. Северна Кореја је, чини се, успела да комбинује ова два мотора ради добијања мотора који би могао покретати већу ракету.

Од марта 2016. године Северна Кореја је открила многе нове детаље у вези са својим интерконтиненталним балистичким ракетама у намери да учврсти кредибилитет њиховог дизајна. Откривена је нова имплозивна нуклеарна бојева глава за ракету KN-08, а затим и детаљи о аблативном материјалу који је употребљен за прекривање бојевих глава за ракете KN-08 и KN-14 који би им омогућавао безбедан поновни улазак у атмосферу.

Аблативни материјали којима је прекривена бојева глава ракете KN-14

Познато је да Северна Кореја има најмање шест интерконтиненталних балистичких ракета типа KN-14 са претпостављеним дометом до 6.000 км.

Седмог априла 2015. године северноамеричка команда ваздухопловне одбране поднела је извештај о томе да је способност севернокорејских интерконтиненталних балистичких ракета, оцењена као „оперативна", али и даље није јасно како је Северна Кореја успела да искомбинује два врло сложена ракетна мотора у један који ће покретати њихове интерконтиненталне балистичке ракете. Кина је, иначе, једина друга држава која је развила покретне интерконтиненталне балистичке ракете на течно гориво у оквиру свог програма DF-14/DF-22.

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Модерне елитне полицијске, војне, односно војно-полицијске јединице за специјалне намене организују се ради оптимизације њихове оперативности и ефикасности, а при извршавању најсложенијих наменских задатака, послова и радњи на оперативном и тактичком нивоу. Ипак, рационализација организације јединице само је једна од нужних претпоставки високе ефикасности. Примарни критеријуми свакако јесу обученост и борбена готовост оперативног кадра, као и доступност поуздане специјалистичке опреме. Уопштено узев, специјалистичка опрема подразумева тактичку опрему намењену за извршавање тактичко-оперативних задатака, послова и радњи у различитим условима, а која се израђује по посебним критеријумима у овој категорији, дакле за потребе јединица за специјалне намене. Последња карактеристика опреме ове врсте нужни је узрок осетно високе цене производње, што потом изискује значајна наменска средства при реализацији набавке. Из тога следи да су у пракси масовније набавке опреме из ове категорије ређе, а најчешће су ограничене на формацијски мање јединице, што, по правилу, важи и за јединице за специјалне намене[13].

Убрзана глобализација[14] и технолошки развој имају и значајан утицај на еволуцију безбедносних изазова, односно безбедносних система који непрекидно изналазе методе којима се супротстављају свим врстама данашњих претњи по безбедност грађана и друштвено-политичких система. Изузетно је важно константно пратити новитете на тржишту наоружања и друге опреме, али и идејне пројекте који су у развоју, као и методе којима се и једна и друга страна служе на терену. Врло често су поједине методе из праксе оцењене као генијалне, а самим тим и веома ефикасне[15], због тога што су биле врло једноставне за припрему и извођење. Ситуациони новитети често су покретали низ сличних метода у пракси, односно узроковали другачије усмеравање ресурса производње наменске индустрије. Имајући то у виду, једноставно је закључити да је праћење и изучавање конструкцијских новитета, идеја, као и практичних метода веома захтеван задатак, који изискује значајне ресурсе у погледу времена, али и шири спектар специјалистичких знања и искустава. Стога модерне јединице за специјалне намене, у оквиру своје структуре, организују и мање специјалистичке групе за конструкцију и испитивање наоружања, муниције, односно специјалистичке тактичке опреме. По правилу, ради се о кадровски мањим групама, чији чланови могу бити и лица из цивилства која располажу изузетним специјалистичким знањима која се постављају као услов

[13] У свету бројније тактичке формације ове врсте најчешће су војног типа, попут специјалних бригада или пукова.
[14] Првенствено у сфери сазнавања и размене информација и искустава.
[15] За страну која је извела одређену методу или скуп метода ефикасност се процењује у односу на узроковане последице, али, наравно, оно што је ефикасно за једну страну, свакако није за супротну.

за рад у групи. Поред тога, чланови ове групе могу бити и активни припадници конкретне јединице, квалификовани изузетним техничким знањима, односно искуством из употребе наоружања и опреме на задужењу у конкретној јединици.

Уопштено, намена ових техничких група дефинише се према намени јединице чији је група организациони део, а по правилу подразумева:

– праћење и анализу дешавања на тржишту у области наоружања, муниције и тактичке опреме, уз посебно изучавање нових конструкцијских решења и анализу пројеката надоградње, тј. модернизације постојећих;

– праћење и анализу искустава из употребе на терену у свим теренско-климатским условима;

– послове и радње редовног одржавања, поправке и унапређивања опреме која је у употреби у конкретној јединици;

– давање стручног мишљења и савета у вези са опремом која је на задужењу у конкретној јединици;

– давање стручног мишљења и савета приликом извођења тестирања, односно приликом доношења одлуке о набавци наоружања, муниције и опреме.

Свеобухватним сагледавањем задатака, послова и радњи које ове специјалистичке групе могу обављати, јасно је колики значај имају у процесу не само опремања конкретних јединица већ и правилног одржавања опреме која је на задужењу, јер претпоставка добре опремљености конкретне јединице и те како подразумева и правилно и редовно одржавање наоружања и опреме у употреби.

Праћење и анализа дешавања на тржишту

У оквиру овог дела активности техничари група прате дешавања активности и произвођача из земље у којој је конкретна јединица устројена, и произвођача из суседних земаља, односно света. Врло је важно истаћи значај праћења пројеката које развијају и промовишу произвођачи суседних земаља.

На основу анализа могу се изразити мишљења и различити предлози. Тако техничари могу давати мишљења конструкторима код националних произвођача о могућим унапређењима постојећих пројеката, или реализацији нових, јер преузимања различитих идеја[16], уз мање или веће измене, данас су врло честа пракса међу произвођачима. Поред тога, на основу практичних решења других произвођача техничари могу самостално унапређивати конструкције које су у употреби у конкретној јединици. На крају, врло је важно истаћи и значај улоге техничара приликом извођења тестирања наоружања и опреме, као и давања коначног мишљења о квалитету, односно приликом одлучивања о набавци новог наоружања и опреме.

[16] Примера ради, српски произвођач „Застава оружје” из Крагујевца је чувену серију полуаутоматских пиштоља „ЦЗ-99” израдио по узору на конструкцију швајцарског „SIG Sauer P-226”.

Пројекти би остали мртво слово на папиру, а конструкције сведене на значај експоната, да се пажња не посвећује искуствима оперативаца са теренске употребе наоружања и друге опреме. Управо ова искуства су најзначајнији критеријум за оцену успешности конкретног пројекта. Они који непосредно користе системе ових врста у свим условима могу изнети најмеродавније мишљење и оцену поузданости и практичности конкретне конструкције. Врло често су и сами оперативци били иницијатори одређених конструкцијских измена, или су на основу њихових критика/сугестија конструктори сами вршили унапређења.

Потискивач затварача на карабину „Colt M-4 A4 Commando" у калибру 5,56 mm, припадника Прве специјалистичке јединице Жандармерије Републике Србије
Фото: Милош Јевтић

Примера ради, велики број притужби корисника познатих америчких карабина „Colt M-4" односио се на застоје услед некомплетног брављења метка. На основу додатних анализа, конструктори су закључили да би се очигледан проблем у раду оружја[17] најрационалније решио додавањем тубуларног потискивача затварача са десне стране сандука пушке, одмах изнад рукохвата.

[17] Нарочито приметан при употреби у условима велике запрљаности.

Редовно одржавање, поправка и унапређивање опреме која је на задужењу у конкретној јединици

Послови и радње редовног одржавања наоружања обавезни су за све припаднике који дуже опрему. Правилно одржавање је једна од претпоставки трајности и поузданости наоружања и друге опреме, стога је правилна обука припадника у овој сфери такође значајна. Обука ове врсте изводи се на самом почетку, по правилу током селекције кандидата за радно место у конкретној јединици, када се припадници и упознају са системима који су у употреби у јединици. У активностима које се тичу одржавања наоружања и друге тактичке опреме припадницима могу асистирати техничари давањем мишљења и савета, односно практичним помагањем. То је посебно значајно приликом изучавања екстремних теренско-климатских услова и њиховог утицаја на „понашање" наоружања и друге опреме, када техничари износе савете о методама заштите система при употреби у овим условима.

Поправка наоружања или друге тактичке опреме изводи се након установљавања неправилног функционисања система, или услед оштећења различитих врста, или једноставно услед дотрајалости дела система. О спроведеним поправкама техничари, по правилу, воде писмену или електронску евиденцију, која такође има вишеструки значај, а након сваке реализоване поправке, посебно ако се радило о интервенцијама већег обима, спроводи се поновно тестирање система, као крајња провера пре враћања припаднику на употребу.

У сарадњи са припадницима јединице техничари специјалистичких група за конструкцију и испитивање наоружања, муниције и опреме могу вршити одређене измене на системима ради унапређивања техничко-тактичких карактеристика. Ова пракса је веома значајна и изводи се у складу са потребама јединице[18], односно индивидуалним потребама припадника који дужи конкретну опрему.

Интервенције на системима могу бити ограничене условима садржаним у купопродајним уговорима, чији су предмет били конкретни системи. Тако, уколико је продавац својом понудом прописао[19] услове под којима се предмет куповине може/мора употребљавати и одржавати, онда се ти услови морају поштовати у пракси. Примера ради, може бити уговорено да се редовно или ванредно сервисирање система спроводи у индивидуално одређеним сервисима, или након одређеног временског периода, или да се не изводе икакве измене на конструкцијама и томе слично.

[18] Посебно када је реч о средствима везе, средствима за обезбеђивање ватрене подршке, механизацији и слично.
[19] Подразумева се да је купац прихватио услове.

Стручно мишљење и савети
у вези са опремом на задужењу

На основу стручног знања, а посебно у случају богатог искуства, техничари су кадри припадницима давати стручна мишљења и савете о начину употребе, одржавања или прилагођавања оружја афинитетима припадника. Овом праксом техничари могу помагати припадницима да боље разумеју техничко-тактичке карактеристике система, да боље схвате „понашање” оружја у свим условима, посебно при екстремним теренско-климатским условима и слично.

Стручно мишљење и савете приликом извођења тестирања,
односно доношења одлуке о набавци

Као што је истакнуто, праћењем дешавања на тржишту техничари могу давати предлоге и о набавци одређених система за потребе тестирања, односно набавке. У том случају они, по правилу, дају и образложења својих предлога, тј. зашто би конкретан тип система био користан за обављање наменских задатака конкретне јединице. Устаљена је пракса да свакој набавци претходи темељно тестирање ради уверавања у квалитет конкретног система. Ипак, у пракси се може десити и да се набавка реализује без претходног тестирања, па чак и саветовања, те се врло често, после одређеног времена употребе, означи као промашај.

Зависно од категорије опреме и/или наоружања, тестирања се изводе различитим методама. Заједничко им је да се изводе у свим условима[20] и да су веома робусна, у смислу да се узета опрема нимало не штеди, тј. излаже се максималним оптерећењима и проверама. Произвођачи чији се производи узимају за потребе тестирања штите своје интересе давањем општих смерница о начину извођења тестирања, које се често означавају фразом „тестирати на рационалан начин, у складу са наменом”[21], уз истовремено упозорење о обавезној накнади штете у случају извођења непримерених метода приликом тестирања. Додатно, паметни произвођачи за потребе тестирања увек пошаљу најквалитетнији контингент својих производа, за које постоји велика вероватноћа да ће задовољити стандарде квалитета.

[20] Такође, обраћа се пажња и да услови тестирања буду приближни реалним, тј. онима који се на одређеном подручју могу најчешће очекивати приликом извођења дејстава.

[21] Примера ради, нерационално тестирање толеранције оружаног система на механичке ударце било би у случају бацања оружја на земљу из авиона.

Детаљ са тестирања тактичког прслука „Dagur”, словеначког произвођача „365 Plus d.o.o.”, рађеног за потребе јединица за специјалне намене
Фото: Милош Јевтић

Тестирање се, по правилу, поверава стручњацима у области у којој се узета опрема употребљава, као и искусним оперативцима који изводе непосредне тестове. Ток тестирања се детаљно бележи и документује фотографијама и видео-записима, што се касније користи и за коначну анализу пре доношења одлуке о набавци, односно одустајању од набавке. Посебно се анализира узрочност техничко-тактичких карактеристика система које наводи произвођач и остварених резултата током тестирања. Крајњи резултати процењују се према намени система који се тестирао, те се изводи процена ефикасности употребе тестираног система приликом обављања наменских задатака, послова и радњи. У извођењу коначне одлуке техничари учествују давањем својих утисака о забележеним резултатима, а од критеријума друге врсте у обзир се узима и цена целих система, као и саставних делова (посебно оних који се највише троше при употреби и чије је сервисирање најчешће), али и фактори политичке природе.

Специјалистичким групама за конструкције и испитивање наоружања, муниције и опреме несумњиво се поверавају веома одговорни послови. Претпоставка квалитетног рада свакако јесте висока стручност и дугогодишње искуство техничара, али и доступност модерног алата и наменских машина помоћу којих техничари могу извршавати свакодневне послове и радње. Боље опремљене јединице располажу и модерним просторијама, у којима се опитовања могу изводити у строго контролисаним условима и на различите начине. Иако не толико упадљиви, техничари ових група веома су важан елемент сваке јединице за специјалне намене и једна од претпоставки њихове оперативности и ефикасности.

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ИСПРАВЛЕНИЯ
ERRATA

1. У *Војнотехничком гласнику*, вол. 64, бр. 2, април–јун 2016. године, у чланку **Negative ions of atoms and diatomic and triatomic molecules / Отрицательные ионы атомов, двухатомных и трехатомных молекул / Negativni joni atoma, dvoatomskih i troatomskih molekula (**doi:10.5937-/vojtehg64-9685) на стр. 447 погрешно је написано презиме првог аутора и име и презиме другог аутора. Уместо Leonid I. Grethcikhin, Viktoriya M. Komarovskaya треба да пише Leonid I. Gretchikhin, Viktoryia M. Kamarouskaya.

2. У *Војнотехничком гласнику*, вол. 63, бр. 3, јул–септембар 2015. године, у чланку **Наведенный потенциал между взаимодействующими частицами на наноуровне / Induced potential between interacting particles at nanolevels / Indukovani potencijal između interaktivnih čestica u nanonivoima (**doi:10.5937/vojtehg63-7721):

– на стр. 29 погрешно је написано име трећег аутора. Уместо Викентия М. Комаровская треба да пише Виктория М. Комаровская;

– на стр. 40 погрешно је написано име трећег аутора. Уместо Vikentija M. Komarovskaja треба да пише Viktorija M. Komarovskaja;

– на стр. 41 погрешно је написано презиме првог аутора и име и презиме трећег аутора. Уместо Leonid I. Gretchihin треба да пише Leonid I. Gretchikhin, а уместо Vikentiya M. Komarovskaya – Viktoryia M. Kamarouskaya.

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1. В журнале «Военно-технический вестник» том 64, № 2, за апрель-июнь 2016 года в статье **Negative ions of atoms and diatomic and triatomic molecules / Отрицательные ионы атомов, двухатомных и трехатомных молекул / Negativni joni atoma, dvoatomskih i troatomskih molekula (**doi:10.5937/vojtehg64-9685) на странице 447 допущена опечатка в фамилии первого автора и имени и фамилии второго автора. Вместо Leonid I. Gretchikhin, Viktoryia M. Kamarouskaya написано Leonid I. Grethcikhin, Viktoriya M. Komarovskaya.

2. В журнале «Военно-технический вестник» том 63, № 3, за июль-сентябрь 2015 года в статье **Наведенный потенциал между взаимодействующими частицами на наноуровне / Induced potential between interacting particles at nanolevels / Indukovani potencijal između interaktivnih čestica u nano nivoima (**doi:10.5937/vojtehg63-7721):

– На странице 29 допущена опечатка в имени третьего автора. Вместо Виктория М. Комаровская написано Викентия М. Комаровская.

– На странице 40 допущена опечатка в имени третьего автора. Вместо Viktorija M. Komarovskaja написано Vikentija M. Komarovskaja.

– На странице 41 допущена опечатка в фамилии первого автора и имени и фамилии третьего автора. Вместо LeonidI. Gretchikhin написано Leonid I. Gretchihin, а вместо Viktoryia M. Kamarouskaya написано – Vikentiya M. Komarovskaya.

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1. In the *Military Technical Courier*, Vol 64, No 2, April-June 2016, in the article

Negative ions of atoms and diatomic and triatomic molecules / Отрицательные ионы атомов, двухатомных и трехатомных молекул / Negativni joni atoma, dvoatomskih i troatomskih molekula (doi:10.5937/vojtehg64-9685) on page 447, the surname of the first author and the name and the surname of the second author are misspelled. Instead of Leonid I. Grethcikhin, Viktoriya M. Komarovskaya, there should be written Leonid I. Gretchikhin, Viktoryia M. Kamarouskaya.

2. In the *Military Technical Courier*, Vol 63, No 3, July-September 2015, in the article

Наведенный потенциал между взаимодействующими частицами нан аноуровне / Induced potential between interacting particles at nanolevels / Indukovani potencijal između interaktivnih čestica u nanonivoima (doi:10.5937/vojtehg63-7721)

– on page 29, the name of the third author is misspelled. Instead of Викентия М. Комаровская, there should be written Виктория М. Комаровская;

– on page 40, the name of the third author is misspelled. Instead of Vikentija M. Komarovskaja, there should be written Viktorija M. Komarovskaja;

– on page 41, the surname of the first author and the name and the surname of the third author are misspelled. Instead of Leonid I. Gretchihin, there should be written Leonid I. Gretchikhin, and instead of Vikentiya M. Komarovskaya–Viktoryia M. Kamarouskaya.

ПОЗИВ И УПУТСТВО АУТОРИМА
ПРИГЛАШЕНИЕ И ИНСТРУКЦИИ ДЛЯ АВТОРОВ РАБОТ
CALL FOR PAPERS AND INSTRUCTIONS FOR AUTHORS

ПОЗИВ И УПУТСТВО АУТОРИМА О НАЧИНУ ПРИПРЕМЕ ЧЛАНКА

Упутство ауторима о начину припреме чланка за објављивање у *Војнотехничком гласнику* урађено је на основу Акта о уређивању научних часописа, Министарства за науку и технолошки развој Републике Србије, евиденциони број 110-00-17/2009-01, од 09. 07. 2009. године. Примена овог Акта првенствено служи унапређењу квалитета домаћих часописа и њиховог потпунијег укључивања у међународни систем размене научних информација. Засновано је на међународним стандардима ISO 4, ISO 8, ISO 18, ISO 215, ISO 214, ISO 18, ISO 690, ISO 690-2, ISO 999 и ISO 5122, односно одговарајућим домаћим стандардима.

Војнотехнички гласник / Vojnotehnički glasnik / Military Technical Courier (втг.мо.упр.срб, www.vtg.mod.gov.rs, ISSN 0042-8469 – штампано издање, e-ISSN 2217-4753 – online, UDC 623+355/359) јесте мултидисциплинарни научни часопис Министарства одбране Републике Србије, који објављује научне и стручне чланке, као и техничке информације о савременим системима наоружања и савременим војним технологијама. Часопис прати јединствену интервидовску техничку подршку Војске на принципу логистичке системске подршке, области основних, примењених и развојних истраживања, као и производњу и употребу средстава наоружања и војне опреме, и остала теоријска и практична достигнућа која доприносе усавршавању припадника Министарства одбране и Војске Србије.

Министарство просвете, науке и технолошког развоја Републике Србије, сагласно одлуци из члана 27. став 1. тачка 4), а по прибављеном мишљењу из члана 25. став 1. тачка 5) Закона о научноистраживачкој делатности („Службени гласник РС“, бр. 110/05, 50/06-испр. и 18/10), утврдило је категоризацију Војнотехничког гласника, за 2013. годину:

за област технолошки развој:

– на листи часописа за материјале и хемијске технологије:

категорија водећи научни часопис националног значаја **(М51)**,

– на листи часописа за електронику, телекомуникације и информационе технологије:

категорија научни часопис националног значаја **(М52)**,

– на листи часописа за машинство:

категорија научни часопис националног значаја **(М52)**,

за област основна истраживања:

– на листи часописа за математику, рачунарске науке и механику:

категорија научни часопис националног значаја **(М52)**.

Усвојене листе домаћих часописа за 2013. годину могу се видети на сајту Војнотехничког гласника, страница Категоризација часописа.

Детаљније информације могу се пронаћи и на сајту Министарства просвете, науке и технолошког развоја Републике Србије.

Подаци о категоризацији могу се пратити и на сајту КОБСОН-а (Конзорцијум библиотека Србије за обједињену набавку).

Категоризација часописа извршена је према Правилнику о поступку и начину вредновања и квантитативном исказивању научноистраживачких резултата истраживача, који је прописао Национални савет за научни и технолошки развој (Службени гласник РС, број 38/2008).

У складу са овим правилником и табелом о врсти и квантификацији индивидуалних научноистраживачких резултата (у саставу Правилника), објављени рад у Војнотехничком гласнику вреднује се са 2 бода (категорија М51) и 1,5 бод (категорија М52).

Часопис се прати у контексту Српског цитатног индекса – СЦиндекс (база података домаћих научних часописа) и Руског индекса научног цитирања (РИНЦ). Подвргнут је сталном вредновању (мониторингу) у зависности од утицајности (импакта) у самим базама и, посредно, у међународним (Thompson Reuters) цитатним индексима. Детаљи о индексирању могу се видети на сајту Војнотехничког гласника, страница Индексирање часописа.

Војнотехнички гласник омогућава и примењује Creative Commons (CC BY) одредбе о ауторским правима. Детаљи о ауторским правима могу се видети на сајту часописа, страница **Ауторска права**.

Радови се предају путем онлајн система за електронско уређивање ASEESTANT, који је развио Центар за евалуацију у образовању и науци (ЦЕОН).

Приступ и регистрација за сервис врше се на сајту www.vtg.mod.gov.rs, преко странице ASEESTANT или СЦИНДЕКС, односно директно на линку

aseestant.ceon.rs/index.php/vtg.

Детаљно упутство о регистрацији и пријави за сервис налази се на сајту www.vtg.mod.gov.rs, страница Упутство за е-Ур: Електронско уређивање – ASEESTANT.

Потребно је да се сви аутори који подносе рукопис за објављивање у Војнотехничком гласнику региструју у регистар ORCID (Open Researcher and Contributor ID), према упутству на страници сајта Регистрација за добијање ORCID идентификационе шифре.

Војнотехнички гласник објављује чланке на српском, енглеском, руском, немачком или француском језику (arial, српска ћирилица или српска латиница, величина слова 11 pt, проред Single).

Поступак припреме, писања и уређивања чланка треба да буде у сагласности са **Изјавом о етичком поступању** (http://www.vtg.mod.gov.rs/izjava-o-etickom-postupanju.html).

Чланак треба да садржи сажетак са кључним речима, увод, разраду, закључак, литературу и резиме са кључним речима на енглеском језику (без нумерације наслова и поднаслова). Обим чланка треба да буде око једног ауторског табака (16 страница формата А4 са проредом Single), а највише 24 странице.

Чланак треба да буде написан на обрасцу за писање чланка, који се у електронској форми може преузети са сајта на страници Образац за писање чланка.

Наслов

Наслов треба да одражава тему чланка. У интересу је часописа и аутора да се користе речи прикладне за индексирање и претраживање. Ако таквих речи нема у наслову, пожељно је да се придода и поднаслов. Наслов треба да буде преведен и на енглески језик.

Ови наслови исписују се испред сажетка на одговарајућем језику.

Текући наслов

Текући наслов се исписује са стране сваке странице чланка ради лакше идентификације, посебно копија чланака у електронском облику. Садржи презиме и иницијал имена аутора (ако аутора има више, преостали се означавају са „et al." или „и др."), наслове рада и часописа и колацију (година, волумен, свеска, почетна и завршна страница). Наслови часописа и чланка могу се дати у скраћеном облику.

Име аутора

Наводи се пуно име и презиме (свих) аутора. Веома је пожељно да се наведу и средња слова аутора. Имена и презимена домаћих аутора увек се исписују у оригиналном облику (са српским дијакритичким знаковима), независно од језика на којем је написан рад.

Назив установе аутора (афилијација)

Наводи се пун (званични) назив и седиште установе у којој је аутор запослен, а евентуално и назив установе у којој је аутор обавио истраживање. У сложеним организацијама наводи се укупна хијерархија (нпр. Универзитет одбране у Београду, Војна академија, Катедра природно-математичких наука). Бар једна организација у хијерархији мора бити правно лице. Ако аутора има више, а неки потичу из исте установе, мора се, посебним ознакама или на други начин, назначити из које од наведених установа потиче сваки од наведених аутора. Афилијација се исписује непосредно након имена аутора. Функција и звање аутора се не наводе.

Контакт подаци

Адреса или е-адреса свих аутора даје се на првој страници чланка.

Категорија (тип) чланка

Категоризација чланака обавеза је уредништва и од посебне је важности. Категорију чланка могу предлагати рецензенти и чланови уредништва, односно уредници рубрика, али одговорност за категоризацију сноси искључиво главни уредник.

Чланци у часописима се разврставају у следеће категорије:

Научни чланци:

1. оригиналан научни рад (рад у којем се износе претходно необјављивани резултати сопствених истраживања научним методом);

2. прегледни рад (рад који садржи оригиналан, детаљан и критички приказ истраживачког проблема или подручја у којем је аутор остварио одређени допринос, видљив на основу аутоцитата);

3. кратко или претходно саопштење (оригинални научни рад пуног формата, али мањег обима или прелиминарног карактера);

4. научна критика, односно полемика (расправа на одређену научну тему, заснована искључиво на научној аргументацији) и осврти.

Изузетно, у неким областима, научни рад у часопису може имати облик монографске студије, као и критичког издања научне грађе (историјско-архивске, лексикографске, библиографске, прегледа података и сл.) – дотад непознате или недовољно приступачне за научна истраживања.

Радови класификовани као научни морају имати бар две позитивне рецензије.

Ако се у часопису објављују и прилози ваннаучног карактера, научни чланци треба да буду груписани и јасно издвојени у првом делу свеске.

Стручни чланци:

1. стручни рад (прилог у којем се нуде искуства корисна за унапређење професионалне праксе, али која нису нужно заснована на научном методу);

2. информативни прилог (уводник, коментар и сл.);

3. приказ (књиге, рачунарског програма, случаја, научног догађаја, и сл.).

Језик рада

Језик рада може бити српски, енглески или други језик који се користи у међународној комуникацији у одређеној научној области (руски, немачки или француски).

Текст мора бити језички и стилски дотеран, систематизован, без скраћеница (осим стандардних). Све физичке величине морају бити изражене у Међународном систему мерних јединица – SI. Редослед образаца (формула) означава се редним бројевима, са десне стране у округлим заградама.

Сажетак (апстракт) и резиме

Сажетак (апстракт) јесте кратак информативан приказ садржаја чланка који читаоцу омогућава да брзо и тачно оцени његову релевантност. У интересу је уредништава и аутора да сажетак садржи термине који се често користе за индексирање и претрагу чланака. Саставни делови сажетка су циљ истраживања, методи, резултати и закључак. Сажетак треба да има од 100 до 250 речи и треба да се налази између заглавља (наслов, имена аутора и др.) и кључних речи, након којих следи текст чланка. Ако је рад написан на српском (руском, немачком или француском) језику пожељно је да се, поред сажетка на српском (руском, немачком или француском), даје и сажетак у проширеном облику на енглеском језику – као тзв. резиме (summary). Овакав резиме треба да буде на крају чланка, након одељка Литература. Важно је да резиме буде у структурираном облику, а његова дужина може бити до 1/10 дужине чланка (опширнији је од сажетка са почетка чланка). Почетак овог резимеа може бити преведени сажетак (са почетка чланка), а затим треба да следе преведени главни наслови, поднаслови и основе закључка чланка (литература се не преводи). Потребно је да се у структурираном резимеу преведе и део текста испод наслова и поднаслова, водећи рачуна да он буде пропорционалан њиховој величини, а да одражава суштину. Након резимеа на енглеском језику (проширеног сажетка) додаје се његов превод на српском, да би редакција извршила проверу и лектуру.

Кључне речи

Кључне речи су термини или фразе које адекватно представљају садржај чланка за потребе индексирања и претраживања. Треба их додељивати ослањајући се на неки међународни извор (попис, речник или тезаурус) који је најшире прихваћен или унутар дате научне области. За нпр. науку уопште, то је листа кључних речи Web of Science. Број кључних речи не може бити већи од 10, а у интересу је уредништва и аутора да учесталост њихове употребе буде што већа. Кључне речи дају се на језику на којем је написан чланак (сажетак) и на енглеском језику. У чланку се пишу непосредно након сажетка, односно након резимеа.

Систем ASEESTANT у ту сврху користи специјалну алатку KWASS: аутоматско екстраховање кључних речи из дисциплинарних тезауруса/речника по избору и рутине за њихов одабир, тј. прихватање односно одбацивање од стране аутора и/или уредника.

Датум прихватања чланка

Датум када је уредништво примило чланак, датум када је уредништво коначно прихватило чланак за објављивање, као и датуми када су у међувремену достављене евентуалне исправке рукописа наводе се хронолошким редоследом, на сталном месту, по правилу на крају чланка.

Захвалница

Назив и број пројекта, односно назив програма у оквиру којег је чланак настао, као и назив институције која је финансирала пројекат или програм, наводи се у посебној напомени на сталном месту, по правилу при дну прве стране чланка.

Претходне верзије рада

Ако је чланак у претходној верзији био изложен на скупу у виду усменог саопштења (под истим или сличним насловом), податак о томе треба да буде наведен у посебној напомени, по правилу при дну прве стране чланка. Рад који је већ објављен у неком часопису не може се објавити у Војнотехничком гласнику (прештампати), ни под сличним насловом и измењеном облику.

Табеларни и графички прикази

Пожељно је да наслови свих приказа, а по могућству и текстуални садржај, буду дати двојезично, на језику рада и на енглеском језику.

Табеле се пишу на исти начин као и текст, а означавају се редним бројевима са горње стране. Фотографије и цртежи треба да буду јасни, прегледни и погодни за репродукцију. Цртеже треба радити у програму word или corel. Фотографије и цртеже треба поставити на жељено место у тексту.

Навођење (цитирање) у тексту

Начин позивања на изворе у оквиру чланка мора бити једнообразан.

Војнотехнички гласник за референцирање (цитирање и навођење литературе) примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual). У самом тексту, у обичним заградама, на месту на којем се врши позивање, односно цитирање литературе набројане на крају чланка, обавезно у обичној загради написати презиме цитираног аутора, годину издања публикације из које цитирате и, евентуално, број страница. Нпр. (Petrović, 2012, pp.10–12).

Детаљно упутство о начину цитирања, са примерима, дато је на страници сајта Упутство за Харвардски приручник за стил. Потребно је да се позивање на литературу у тексту уради у складу са поменутим упутством.

Систем ASEESTANT у сврху контроле навођења (цитирања) у тексту користи специјалну алатку CiteMatcher: откривање изостављених цитата у тексту рада и у попису референци.

Напомене (фусноте)

Напомене се дају при дну стране на којој се налази текст на који се односе. Могу садржати мање важне детаље, допунска објашњења, назнаке о коришћеним изворима (на пример, научној грађи, приручницима), али не могу бити замена за цитирану литературу.

Листа референци (литература)

Цитирана литература обухвата, по правилу, библиографске изворе (чланке, монографије и сл.) и даје се искључиво у засебном одељку чланка, у виду листе референци. Референце се не преводе на језик рада и набрајају се у посебном одељку на крају чланка.

Војнотехнички гласник, као начин исписа литературе, примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual).

Литература се обавезно пише на латиничном писму и набраја по абецедном редоследу, наводећи најпре презимена аутора, без нумерације.

Детаљно упутство о начину пописа референци, са примерима, дато је на страници сајта Упутство за Харвардски приручник за стил. Потребно је да се попис литературе на крају чланка уради у складу са поменутим упутством.

Нестандардно, непотпуно или недоследно навођење литературе у системима вредновања часописа сматра се довољним разлогом за оспоравање научног статуса часописа.

Систем ASEESTANT у сврху контроле правилног исписа листе референци користи специјалну алатку RefFormatter: контрола обликовања референци у складу са Харвардским приручником за стил.

Пропратно писмо

Поред чланка доставља се пропратно писмо у којем треба истаћи о којој врсти чланка се ради, који су графички прилози (фотографије и цртежи) оригинални, а који позајмљени.

У пропратном писму наводе се и подаци аутора: име, средње слово, презиме, чин, звање, е-маил, адреса послодавца (ВП), кућна адреса, телефон на радном месту и кућни (мобилни) телефон, рачун и назив банке, СО места становања, број личне карте и ЈМБ грађана.

Ако је више аутора чланка, у пропратном писму се наводи појединачни процентуални удео ради обрачуна хонорара.

Сви радови подлежу стручној рецензији, а објављени радови и стручне рецензије хоноришу се према важећим прописима.

Списак рецензената Војнотехничког гласника може се видети на страници сајта **Списак рецензената**. Процес рецензирања објашњен је на страници сајта **Рецензентски поступак**.

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ПРИГЛАШЕНИЕ И ИНСТРУКЦИЯ ДЛЯ АВТОРОВ О ПОРЯДКЕ ПОДГОТОВКИ СТАТЬИ

Инструкция для авторов о порядке подготовки статьи к опубликованию в журнале «Военно-технический вестник» разработана в соответствии с Актом о редактировании научных журналов Министерства науки и технологического развития Республики Сербия, № 110-00-17/2009-01 от 09.07.2009 г. Применением этого Акта, в первую очередь, обеспечивается совершенствование качества отечественных журналов и их более полного включения в международную систему обмена научной информацией. Инструкция соответствует международным стандартам ISO 4, ISO 8, ISO 18, ISO 215, ISO 214, ISO 18, ISO 690, ISO 690-2, ISO 999, ISO 5122 и соответствующим отечественным стандартам.

Военно-технический вестник (**Vojnotehnički glasnik / Military Technical Courier**), втг.мо.упр.срб, www.vtg.mod.gov.rs/index-ru.html, ISSN 0042-8469 – печатное издание, e-ISSN 2217-4753 – online, UDK 623+355/359, является мультидисциплинарным научным журналом Министерства обороны Республики Сербия, публикующий научные статьи и статьи специалистов, в том числе технические информации относительно современных систем вооружения и современных военных технологиях. Журнал отслеживает за единственной интервидовой технической поддержкой вооруженных сил на принципах логистической поддержки, в области основных применяемых научных исследований, а также в области производства вооружений и военного оборудования и остальных теоретических и практических достижений, содействующих повышению квалификаций персонала Министерства Обороны и Вооруженных сил Республики Сербия.

Министерство образования, науки и технологического развития Республики Сербия, согласно решению по ст. 27 абзац 1, пункт 4 и по полученному толкованию ст. 25 абзац 1 пункт 5 Закона о научно-исследовательской деятельности („Службени гласник РС", № 110/05, утверждило категоризацию Военно-технического вестника за 2013 год:

Категории в области технологического развития:

– Область материалов и химической технологии:

ведущий научный журнал национального значения **(M51)**,

– Область электроники, телекоммуникаций и информационных технологий: научный журнал национального значения **(M52)**,

– Область механики:

научный журнал национального значения **(M52)**.

Категории в области основных исследований:

– Область математика, компьютерные науки, технические науки:

научный журнал национального значения **(M52)**.

Информацию относительно категоризации за 2013 год можно посмотреть на странице сайта Военно-технического вестника Категоризация вестника.

Более подробную информацию можно прочитать на сайте Министерства образования, науки и технологического развития Республики Сербия.

Информацию о категоризации можно посмотреть и на сайте КОБСОН-а (Консорциум библиотек Республики Сербия по вопросам объединения закупок).

Категоризация вестника проведена согласно Положению о порядке и способе категоризации научно-исследовательских результатов, утвержденному Национальным комитетом по науке и технологиям (Службени гласник РС, № 38/2008).

В соответствии с вышеуказанным Положением и табличкой с показателями классификации и категоризации индивидуальных научно-исследовательских результатов (являющейся неотъемлемой частью Положения), работа, опубликованная в Военно-техническом вестнике, оценивается следующим способом: 2 балла (категория M51) и 1,5 баллов (категория M52).

Журнал соответствует стандартам Сербского цитатного индекса – SCindeks (база данных отечественных научных журналов), а также Российского индекса научного цитирования (РИНЦ). Журнал постоянно оценивается (мониторинг) в зависимости от численного показателя важности научного журнала в самих базах, в т.ч. опосредованно в международных цитатных индексах (Thompson Reuters).

С информацией об индексировании можно ознакомиться на странице сайта журнала «Индексирование вестника».

«Военно-технический вестник» обеспечивает читателям возможность открытого доступа, в соответствии с положениями об авторских правах, утвержденными Creative Commons (CC BY). С инструкцией об авторских правах можно ознакомиться на странице **Авторские права**, перейдя по ссылке http://www.vtg.mod.gov.rs/index-ru.html.

Работы представляются путем online системой e-Ур: Электронное издательство ASEESTANT, запущенное Центром поддерживающим развитие образования и науки (ЦЕОН).

Права доступа и регистрация в системе оформляются по адресу http://www.vtg.mod.gov.rs/index-ru.html, через страницу «ASEESTANT» или «СЦИНДЕКС» (aseestant.ceon.rs/index.php/vtg).

С инструкцией по регистрации и праву доступа можно ознакомиться по адресу http://www.vtg.mod.gov.rs/index-ru.html, на странице «Инструкция по e-Ур: Электронное издательство ASEESTANT».

Все авторы, предоставляющие свои рукописи на публикацию в редакцию журнала «Военно-технический вестник» должны пройти регистрацию в реестре ORCID (Open Researcher and Contributor ID), в соответствии с инструкцией на странице сайта Регистрация в реестре ORCID для присвоения идентификационного кода.

Военно-технический вестник выпускает статьи на сербском, русском, английском, немецком или французском языках (Arial, шрифт 11 pt, пробел Single).

Процесс подготовки, написания и редактирования статьи должен осуществляться в соответствии с принципами **Этического кодекса** (http://www.vtg.mod.gov.rs/etichyeskiy-kodyeks.html).

Статья должна содержать сюжет с ключевыми словами, введение, разработку, выводы, список использованной литературы и резюме с ключевыми словами на английском языке (без нумерации заголовков и подзаголовков). Объем статьи не должен превышать один авторский лист (16 страниц формата A4 с пробелом Single).

Статья должна быть написана на образце написания статьи, который можно скачать на странице сайта «Правила и образец составления статьи».

Заголовок

Заголовок должен отражать тему статьи. Интересы журнала и автора состоят в использовании слов, удобных для индексации и поиска. Если такие слова не содержаны в заголовке, то желательно добавить и подзаголовок. Заголовок должен быть переведен на английский язык. Эти заголовки пишутся перед сюжетами на соответствующем языке.

Текущий заголовок

Текущий заголовок пишется в титуле каждой страницы статьи с целью упрощения идентификации, в первой очереди копий статьей в электронном виде. Содержит в себе фамилию и инициал имени автора (в случае если авторов несколько, остальные обозначаются с «et al.» или «и др.»), заголовки работы и журнала (год, объем, тетрадь, начальная и заключительная страница). Заголовки журнала и статьи могут приводиться в сокращенном виде.

ФИО автора

Приводятся полная фамилия и полное имя (всех) авторов. Очень желательно, чтобы были приведены и средние буквы авторов. Фамилия и имя отечественных авторов всегда пишутся в оригинальном виде (с сербскими диакритическими знаками), независимо от языка, на котором работа написана.

Наименование учреждения автора (аффилиация)

Приводится полное (официальное) наименование и местонахождение учреждения, в котором работает автор, а также наименование учреждения, в котором автор провел исследование. В случае сложных организаций приводится общая иерархия (напр. Университет обороны в г. Белграде, Военная академия, Кафедра военных электронных систем). По крайней мере, одна из этих организаций в иерархии должна иметь статус юридического лица. В случае если авторов несколько, и если некоторые работают в одном учреждении, нужно отдельными обозначениями или каким-нибудь другим способом указать в каком из приведенных учреждений работает каждый из - приведенных авторов. Аффилиация пишется непосредственно после ФИО автора. Должность и квалификация по образованию не указываются.

Контактные данные

Почтовый адрес и/или электронный адрес авторов указываются на первой страницы статьи.

Категория (тип) статьи

Категоризация статьей является обязанностью редакции и имеет особое значение. Категорию статьи могут предлагать рецензенты и члены редакции, т.е. редакторы рубрик, но ответственность за категоризацию несет исключительно главный редактор. Статьи в журналах распределяются по следующим категориям:

Научные статьи:

1. оригинальная научная работа (работа, в которой приводятся раньше неопубликованные результаты собственных исследований научным методом);
2. наглядная работа (работа, содержащая оригинальный, детальный и критический обзор исследовательской проблемы или области, в который автор внес определенный вклад, видимый на основе автоцитат);
3. краткая или предварительная информация (оригинальная научная работа полного формата, но меньшего объема или имеющая предварительный характер);
4. научная критика, т.е. полемика (дискуссия на определенную научную тему, обоснованная исключительно на научной аргументации) и беглые обзоры.

Однако, в некоторых областях научная работа в журнале может иметь форму монографической студии, а также критического издания научного материала (историко-архивного, лексикографического, библиографического, обзора данных и т.п.) – до тех пор неизвестного или недостаточно доступного для научных исследований. Работы, классифицированные в качестве научных, должны иметь, по меньшей мере, две положительные рецензии.

В случае если в журнале объявляются и приложения, не имеющие научный характер, научные статьи должны быть сгруппированы и четко выделены в первой части тетради.

Профессиональные статьи:

1. профессиональная работа (приложения, в которых предлагаются опыты, полезные для совершенствования профессиональной практики, но которые не должны в обязательном порядке быть обоснованы на научном методе);
2. информативное приложение (передовая статья, комментарий и т.п.);
3. рецензия (книги, компьютерной программы, случая, научного события и т.п.).

Язык работы

Работа может быть написана на сербском, английском или другом языке, используемом в международной коммуникации в определенной научной области (русский, немецкий или французский).

Текст должен быть в лингвистическом и стилистическом смысле упорядочен, систематизирован, без сокращений (за исключением стандартных). Все физические величины должны соответствовать Международной системе единиц измерения – СИ. Очередность формул обозначается порядковыми номерами, с правой стороны в круглых скобках.

Сюжет (абстракт) и резюме

Сюжет (абстракт) является кратким информативным обзором содержания статьи, обеспечивающим читателю быстро и точно оценить его релевантность. В интересах редакции и авторов, чтобы сюжет содержал термины, часто используемые для индексирования и поиска статьей. Составными частями сюжета являются цель исследования, методы и заключение. В сюжете должно быть от 100 до 250 слов, и должен находится между титулами (заголовок, ФИО авторов и др.) и ключевыми словами, за которыми следует текст статьи. Если работа написана на сербском (русском, немецком или французском) языке, желательно, чтобы кроме сюжета на сербском (русском, немецком или французском) был предоставлен и сюжет в расширенном виде на английском языке – в качестве т.н. резюме (summary). Такой резюме должен находиться в конце статьи, после раздела Литература. Важно, чтобы резюме было в структурированном виде, и его длина может составлять до 1/10 длины статьи (оно более обширно, чем сюжет из начала статьи). Началом данного резюме может быть переведенный сюжет (из начала статьи), а затем должны следовать переведенные главные заголовки, подзаголовки и основы заключения статьи (литература не переводится). В структурированном резюме нужно перевести часть текста под заголовком и заголовком, принимая во внимание, чтобы она была пропорциональна их размеру и в то же время отражала суть.

Ключевые слова

Ключевыми словами являются термины или фразы, адекватно представляющие содержание статьи, необходимое для индексирования и поиска. Их надо присуждать, опираясь при этом на какой-то международный источник (регистр, словарь, тезаурус), наиболее приемлемый внутри данной научной области. Число ключевых слов не может превышать 10, а в интересах редакции и авторов, чтобы их частота была как можно больше. Ключевые слова даются на языке, на котором написана статья (сюжет), и на английском языке. В статье они пишутся непосредственно после сюжета, т.е. после резюме.

Программа ASSESTANT предоставляет возможность использования сервиса KWASS: автоматическое фиксирование ключевых слов из источников/словарей по выбору, т.е., которые автор/редактор воспринимает или нет.

Дата получения статьи

Дата, когда редакция получила статью, дата, когда редакция окончательно приняла статью для опубликования, а также даты, когда за истекший период были предоставлены эвентуальные исправления рукописи, приводятся в хронологическом порядке, на постоянном месте, как правило, в конце статьи.

Выражение благодарности

Наименование и номер проекта, т.е. название программы, в которой статья возникла, как и наименование учреждения, которое финансировало проект или программу, приводятся в отдельном примечании на постоянном месте, как правило, внизу первой страницы статьи.

Предыдущие версии работы

В случае если статья в предыдущей версии была изложена в устном обращении (-под одинаковым или похожим названием), сведение об этом должно быть указано в отдельном примечании, как правило, внизу первой страницы статьи. Работа, которая уже опубликована в некотором из журналов, не может быть опубликована в Военно-техническом вестника (перепечатана), ни под похожим названием, ни измененном виде.

Табличное и графическое представление

Желательно, чтобы названия всех представлений (по возможности и текстуальное содержание) были представлены на двух языках (на языке работы и на английском). Таблицы пишутся таким же способом как и текст и обозначаются порядковыми номерами с верхней стороны. Фотографии и рисунки должны быть понятны, наглядны и удобные для репродукции. Рисунки надо делать в программах Word или corel. Фотографии и рисунки надо поставить на желаемое место в тексте.

Ссылки (цитирование) в тексте

Оформление ссылок на источники в рамках статьи должно быть однообразным.

Военно-технический вестник для оформления ссылок, цитат и списка использованной литературы пользуется гарвардской системой (Harvard Referencing System, Harvard Style Manual). В тексте в скобках приводится фамилия цитируемого автора (или фамилия первого автора, если авторов несколько), год издания и по необходимости номер страницы. Например: (Петрович, 2010., пп. 10-20). Рекомендации о способе цитирования размещены на странице сайта «Инструкция по использованию Гарвардского стиля». При оформлении ссылок, цитат и списка использованной литературы необходимо придерживаться установленных норм.

Программа ASEESTANT предоставляет при цитировании возможность использования сервиса CiteMatcher: фиксирование пропущенных цитат в работе и списке литературы.

Примечания (сноски)

Примечания указываются внизу страницы, на которой находится текст, к которым они относятся. Могут содержать менее важные детали, дополнительные объяснения, указания об использованных источниках (напр. научном материале, справочниках), но не могут быть заменой для цитированной литературы.

Лист референций (литература)

Цитированной литературой охвачены, как правило, библиографические источники (статьи, монографии и т.п.) и она представляется исключительно в отдельном разделе статьи, в виде листа референций. Референции не переводятся на язык работы.

Военно-технический вестник для оформления списка использованной литературы применяет гарвардскую систему (Harvard Style Manual). В списке литературы источники даются в алфавитном порядке авторов или редакторов. Рекомендации о способе цитирования размещены на странице сайта «Инструкция по использованию Гарвардского стиля». При оформлении списка использованной литературы необходимо придерживаться установленных норм.

Программа ASEESTANT при оформлении списка литературы предоставляет возможность использования сервиса RefFormatter: контроль оформления списка литературы в соответствии со стандартами Гарвардского стиля.

Нестандартное, неполное и непоследовательное приведение литературы в системах оценки журнала считается достаточной причиной для оспаривания научного статуса журнала.

Сопроводительное письмо

Кроме статьи предоставляется сопроводительное письмо, в котором нужно указать о каком виде статьи речь идет, которые из графических представлений (фотографии и рисунки) оригинальные, а которые взяты взаймы.

В сопроводительном письме приводятся и сведения об авторе: имя, средняя буква, фамилия, чин, звание, e-mail, адрес работодателя (воинская почта), домашний адрес, служебный телефон и личный (мобильный) телефон, счет и наименование банка, муниципалитет места проживания и единый идентификационный номер гражданина.

В случае если авторов статьи несколько, в сопроводительном письме указывается доля участия каждого из них отдельно в процентах, в целях расчета гонорара.

Все работы подлежат спец. рецензированию, в то время как опубликованные работы и спец. рецензии оплачиваются согласно действующему законодательству.

Список рецензентов Военно-технического вестника можно посмотреть на странице сайта **Список рецензентов**. Процесс рецензирования описан на странице сайта **Правила рецензирования**.

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CALL FOR PAPERS AND ARTICLE FORMATTING INSTRUCTIONS

The instructions to authors about the article preparation for publication in the *Military Technical Courier* are based on the Act on scientific journal editing of the Ministry of Science and Technological Development of the Republic of Serbia, No 110-00-17/2009-01 of 9th July 2009. This Act aims at improving the quality of national journals and raising the level of their compliance with the international system of scientific information exchange. It is based on international standards ISO 4, ISO 8, ISO 18, ISO 215, ISO 214, ISO 18, ISO 690, ISO 690-2, ISO 999 and ISO 5122 and their national equivalents.

The Military Technical Courier / Vojnotehnički glasnik (www.vtg.mod.gov.rs/index-e.html, втг.мо.упр.срб, ISSN 0042-8469 – print issue, e-ISSN 2217-4753 – online, UDC 623+355/359) is a multidisciplinary scientific journal of the Ministry of Defence of the Republic of Serbia. It publishes scientific and professional papers as well as technical data about contemporary weapon systems and modern military technologies. Offering a logistic system support, the *Courier* is a part of a unique technical support to the Army services in the field of fundamental, applied and development research. It also deals with production and use of weapons and military equipment as well as with theoretical and practical achievements leading to professional development of the personnel of the Ministry of Defence and the Army of the Republic of Serbia.

Pursuant to the decision given in Article 27, paragraph 1, point 4, and in accordance with the acquired opinion given in Article 25, paragraph 1, point 5 of the Act on Scientific and Research Activities (Official Gazette of the Republic of Serbia, No 110/05, 50/06-cor and 18/10), the Ministry of Education, Science and Technological Development of the Republic of Serbia classified the Military TechnIcal Courier for the year 2013

in the field technological development:
– on the list of periodicals for materials and chemical technology,
category: leading scientific periodical of national interest **(M51)**,
– on the list of periodicals for electronics, telecommunications and IT,
category: scientific periodical of national interest **(M52)**,
– on the list of periodicals for mechanical engineering,
category: scientific periodical of national interest **(M52)**,
in the field fundamental research:
– on the list of periodicals for mathematics, computer sciences and mechanics,
category: scientific periodical of national interest **(M52)**.

The approved lists of national periodicals for the year 2013 can be viewed on the website of the Military Technical Courier, page Journal categorization.

More detailed information can be found on the website of the Ministry of Education, Science and Technological Development of the Republic of Serbia.

The information on the categorization can be also found on the website of KOBSON (Consortium of Libraries of Serbia for Unified Acquisition).

The periodical is categorized in compliance with the Regulations on the procedure and method of evaluation and quantitative formulation of scientific and research results of researchers, stipulated by the National Council for Scientific and Technological Development (*Official Gazette of RS*, No 38/2008). More detailed information can be found on the website of the Ministry of Education, Science and Technological Development.

In accordance with the Regulations and the table about types and quantification of individual scientific and research results (as a part of the Regulations), a paper published in the *Military Technical Courier* scores 2 (two) points (category M51) and 1,5 (one and a half) point (category M52).

The journal is in the Serbian Citation Index – SC index (data base of national scientific journals), in the Russian Science Citation Index (RSCI) and is constantly monitored depending on the impact within the bases themselves and indirectly in the international (e.g. Thompson Reuters) citation indexes. More detailed information can be viewed on the website of the Military Technical Courier, page Journal indexing.

Military Technical Courier enables open access and applies the Creative Commons Attribution (CC BY) licence provisions on copyright. The copyright details can be found on the **Copyright notice** page of the journal's website.

Manuscripts are submitted online, through the electronic editing system ASEESTANT, developed by the Center for Evaluation in Education and Science – CEON.

The access and the registration are through the Military Technical Courier site http://www.vtg.mod.gov.rs/index-e.html, on the page ASEESTANT or the page SCINDEKS or directly through the link (aseestant.ceon.rs/index.php/vtg).

The detailed instructions about the registration for the service are on the website http://www.vtg.mod.gov.rs/index-e.html, on the page Instructions for e-Ur: Electronic Editing - ASEESTANT.

All authors submitting a manuscript for publishing in the Military Technical Courier should register for an ORCID ID following the instructions on the web page Registration for an ORCID identifier.

The Military Technical Courier publishes articles in Serbian, English, Russian, German or French, using Arial and a font size of 11pt with Single Spacing.

The procedures of article preparation, writing and editing should be in accordance with the **Publication ethics statement**. (http://www.vtg.mod.gov.rs/publication-ethics-statement.html).

The article should contain the abstract with keywords, introduction, body, conclusion, references and the summary in English language (without heading and subheading enumeration). The article length should not exceed 24 pages of A4 paper format.

The article should be formatted following the instructions in the Article Form which can be downloaded from website page Article form.

Title

The title should be informative. It is in both Journal's and author's best interest to use terms suitable for indexing and word search. If there are no such terms in the title, the author is strongly advised to add a subtitle. The title should be given in English as well.

The titles precede the abstract and the summary in an appropriate language.

Letterhead title

The letterhead title is given at a top of each page for easier identification of article copies in an electronic form in particular. It contains the author's surname and first name initial (for multiple authors add "et al"), article title, journal title and collation (year, volume, issue, first and last page). The journal and article titles can be given in a shortened form.

Author's name

Full name(s) of author(s) should be used. It is advisable to give the middle initial. Names are given in their original form (with diacritic signs if in Serbian).

Author's affiliation

The full official name and seat of the author's affiliation is given, possibly with the name of the institution where the research was carried out. For organizations with complex structures, give the whole hierarchy (for example, University of Defence in Belgrade, Military Academy, Department for Military Electronic Systems). At least one organization in the hierarchy must be a legal entity. When some of multiple authors have the same affiliation, it must be clearly stated, by special signs or in other way, which department exactly they are affiliated with. The affiliation follows the author's name. The function and title are not given.

Contact details

The postal addresses or the e-mail addresses of the authors are given in the first page.

Type of articles

Classification of articles is a duty of the editorial staff and is of special importance. Referees and the members of the editorial staff, or section editors, can propose a category, but the editor-in-chief has the sole responsibility for their classification.

Journal articles are classified as follows:

Scientific articles:

1. Original scientific paper (giving the previously unpublished results of the author's own research based on scientific methods);
2. Survey paper (giving an original, detailed and critical view of a research problem or an area to which the author has made a contribution visible through his self-citation);
3. Short or preliminary communication (original scientific paper of full format but of a smaller extent or of a preliminary character);
4. Scientific critique or forum (discussion on a particular scientific topic, based exclusively on scientific argumentation) and commentaries.

Exceptionally, in particular areas, a scientific paper in the Journal can be in a form of a monograph or a critical edition of scientific data (historical, archival, lexicographic, bibliographic, data survey, etc.) which were unknown or hardly accessible for scientific research.

Papers classified as scientific must have at least two positive reviews.

If the journal contains non-scientific contributions as well, the section with scientific papers should be clearly denoted in the first part of the Journal.

Professional articles:

1. Professional paper (contribution offering experience useful for improvement of professional practice but not necessarily based on scientific methods);
2. Informative contribution (editorial, commentary, etc.);
3. Review (of a book, software, case study, scientific event, etc.)

Language

The article can be in Serbian, English or other language used in international communication in a particular scientific field (Russian, German or French).

The grammar and style of the article should be of good quality. The systematized text should be without abbreviations (except standard ones). All measurements must be in SI units. The sequence of formulae is denoted in Arabic numerals in parentheses on the right-hand side.

Abstract and summary

An abstract is a concise informative presentation of the article content for fast and accurate evaluation of its relevance. It is both in the Editorial Office's and the author's best interest for an abstract to contain terms often used for indexing and article search. The abstract describes the purpose of the study and the methods, outlines the findings and state the conclusions. A 100- to 250- word abstract should be placed between the title and the keywords with the body text to follow. Besides an abstract in Serbian (Russian, German or French), articles in Serbian (Russian, German or French) are advised to have a summary in English, at the end of the article, after the Reference list. The summary should be structured and long up to 1/10 of the article length (it is more extensive than the abstract). It can start with the translated Serbian (Russian, German or French) abstract from the beginning of the article with translated main headings, subheadings and major conclusions to follow (Reference list is not translated). The structured summary should also contain the proportional informative parts of the text below the headings and subheadings.

Keywords

Keywords are terms or phrases showing adequately the article content for indexing and search purposes. They should be allocated heaving in mind widely accepted international sources (index, dictionary or thesaurus), such as the Web of Science keyword list for science in general. The higher their usage frequency is, the better. Up to 10 keywords immediately follow the abstract and the summary, in respective languages.

For this purpose, the ASEESTANT system uses a special tool KWASS for the automatic extraction of key words from disciplinary thesauruses/dictionaries by choice and the routine for their selection, i.e. acceptance or rejection by author and/or editor.

Article acceptance date

The date of the reception of the article, the dates of submitted corrections in the manuscript (optional) and the date when the Editorial Board accepted the article for publication are all given in a chronological order at the end of the article.

Acknowledgements

The name and the number of the project or programme within which the article was realised is given in a separate note at the bottom of the first page together with the name of the institution which financially supported the project or programme.

Article preliminary version

If an article preliminary version has appeared previously at a meeting in a form of an oral presentation (under the same or similar title), this should be stated in a separate note at the bottom of the first page. An article published previously cannot be published in the *Military Technical Courier* even under a similar title or in a changed form.

Tables and illustrations

All the captions should be in the original language as well as in English, together with the texts in illustrations if possible. Tables are typed in the same style as the text and are denoted by Arabic numerals at the top. Photographs and drawings, placed appropriately in the text, should be clear, precise and suitable for reproduction. Drawings should be created in Word or Corel.

Citation in the text

Citation in the text must be uniform. The Military Technical Courier applies the Harvard Referencing System given in the Harvard Style Manual. When citing sources within your paper, i.e. for in-text references of the works listed at the end of the paper, place the year of publication of the work in parentheses and optionally the number of the page(s) after the author's name, e.g. (Petrovic, 2012, pp.10-12). A detailed guide on citing, with examples, can be found on Military Technical Courier website on the page Instructions for Harvard Style Manual. In-text citations should follow its guidelines.

For checking in-text citations, the ASESESTANT system uses a special tool CiteWatcher to find out quotes left out within papers and in reference lists.

Footnotes

Footnotes are given at the bottom of the page with the text they refer to. They can contain less relevant details, additional explanations or used sources (e.g. scientific material, manuals). They cannot replace the cited literature.

Reference list (Literature)

The cited literature encompasses bibliographic sources such as articles and monographs and is given in a separate section in a form of a reference list.

References are not translated to the language of the article.

In compiling the reference list and bibliography, the Military Technical Courier applies the Harvard System – Harvard Style Manual. All bibliography items should be listed alphabetically by author's name, without numeration. A detailed guide for listing references, with examples, can be found on Military Technical Courier website on the page Instructions for Harvard Style Manual. Reference lists at the end of papers should follow its guidelines.

In journal evaluation systems, non-standard, insufficient or inconsequent citation is considered to be a sufficient cause for denying the scientific status to a journal.

The covering letter

The article should be accompanied with a cover letter with the information about the author(s): surname, middle initial, first name, citizen personal number, rank, title, e-mail address, affiliation address, home address including municipality, phone number in the office and at home (or a mobile phone number), bank account and the name of the bank.

If there are more authors, their share in the article should be given in percents for honorarium calculation purposes.

The cover letter should state the type of the article and tell which illustrations are original and which are not.

All articles are peer reviewed. All authors and reviewers are paid an honorarium on publication of the article.

The list of referees of the Military Technical Courier can be viewed at website page **List of referees**. The article review process is described on the **Peer Review Process** page of the website.

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ОБАВЕШТЕЊА САРАДНИЦИМА И ЧИТАОЦИМА
INFORMATIONS FOR CONTRIBUTORS AND READERS
СООБЩЕНИЯ ДЛЯ ПАРТНЕРОВ И ЧИТАТЕЛЕЙ

ЦЕОН доделио *Војнотехничком гласнику* ознаку „кк (контрола квалитета)” четврту годину за редом

Центар за евалуацију у образовању и науци (ЦЕОН, http://ceon.rs/index.php/sr/), издавач Српског цитатног индекса (http://scindeks.ceon.rs/), публиковао је Библиометријски извештај о научним часописима за 2015. годину. У складу с устаљеном праксом, о томе је обавештено надлежно министарство у Влади Републике Србије, како би се резултати употребили у складу с Правилником о вредновању, односно утврдила категоризација домаћих научних часописа за 2016. годину.

Библиометријски извештај за 2015. годину је кумулативног карактера – обухвата податке за период од 2002. надаље.

ЦЕОН је и у овогодишњем Библиометријском извештају, као и у извештајима за 2012, 2013 и 2014. годину доделио Војнотехничком гласнику ознаку „кк (контрола квалитета посредством ЦЕОН Асистента)” која означава контролисани квалитет часописа у систему евалуације. *Војнотехнички гласник* је један од првих часописа у Српском цитатном индексу који је добио ову ознаку.

Центр ЦЕОН присвоил журналу «Военно-технический вестник» знак качества «кк» (контроль качества). Данный знак присваивается журналу «Военно-технический вестник» уже четвертый год подряд

Центр по эвальвации в области науки и образования (ЦЕОН, http://ceon.rs/index.php/sr/) − издатель Сербского индекса научного цитирования (http://scindeks.ceon.rs/), опубликовал Библиометрическую оценку научных журналов, выпущенных в течение 2015 года. Согласно утвержденным нормам и правилам о результатах исследования проинформировано компетентное министерство Правительства Республики Сербия с целью их дальнейшего применения в области категоризации отечественных научных журналов в 2016 году, согласно Положению о категоризации. Библиометрическая оценка научных журналов за 2015 год имеет кумулятивный характер и ею охвачены данные за период с 2002 года.

Центр ЦЕОН в Библиометрическом отчете текущего года, а также в отчетах за 2012, 2013 и 2014 годы присвоил журналу «Военно-технический вестник» знак качества «КК» (контроль качества путем приложения ЦЕОН Ассистент)», данным знаком обозначается контрольное качество публикации в системе эвальвации. Журнал «Военно-технический вестник» является одной из первых публикаций в Сербском индексе научного цитирования, удостоенной присвоения данного знака.

CEON has marked *The Military Technical Courier* with “kk (quality control)” for the fourth year in a row

The Center for Evaluation in Education and Science (CEON, http://ceon.rs/index.php/en/), publisher of the Serbian Citation Index (http://scindeks.ceon.rs/default.aspx?lang=en), published the Bibliometric Report on Scientific Journals for year 2015. In compliance with established practice, the relevant ministry in the government of the Republic of Serbia was notified so that the results could be dealt with in accordance with the Regulation on Validation, i.e. so that national journals could be classified for 2016.

The Bibliometric Report for 2015 is of cumulative nature, encompassing the data from 2002 to the present.

In this year’s Bibliometric Report, as well as in its 2012, 2013 and 2014 Reports, the CEON marked *The Military Technical Courier* with “kk (quality control through the CEON Aseestant system)” which represents the controlled quality of a journal in this evaluation system. *The Military Technical Courier* is one of the first journals in the Serbian Citation Index to obtain it.

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1.	JEMC	100,00	7,00	26,67	100,00
2.	Kragujevac J Mathematics	100,00	7,00	95,45	100,00
3.	Sci Pub Univ Novi Pazar		,93	50,00	100,00
4.	Vojnotehnički glasnik kk	100,00	9,50	23,81	35,71

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