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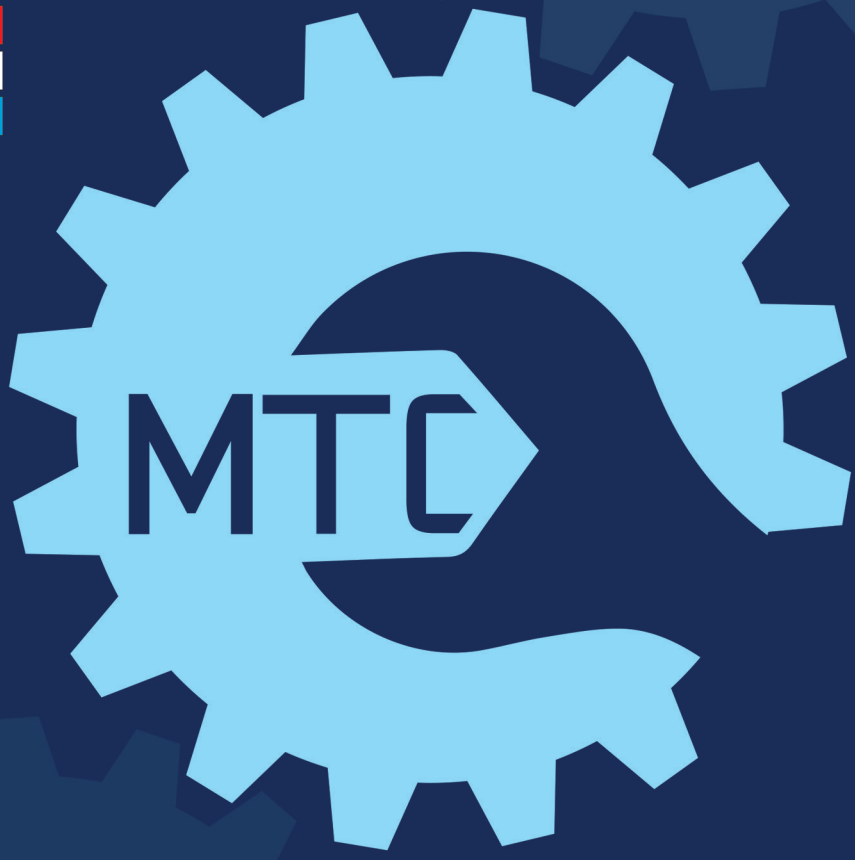

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С А Д Р Ж А Ј

С О Д Е Р Ж А Н И Е

C O N T E N T S

A NEW OPERATION ON SOFT SETS: EXTENDED SYMMETRIC DIFFERENCE OF SOFT SETS

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Abstract:

Introduction/purpose: Molodtsov introduced the concept of soft sets as a new mathematical tool for dealing with problems containing uncertainties. In the literature, different kinds of operations of soft sets are defined and used in theory and applications.

Methods: This study is based on the paper "A New Operation on Soft Sets: Extended Difference of Soft Sets" by Sezgin, Ahmad and Mehmood [Journal of New Theory 27 (2019) 33-42].

Results: In this paper, we define a new operation on soft sets, called extended symmetric difference and investigate its relationship between extended symmetric difference and restricted symmetric difference and some other operations of soft sets.

Conclusion: The author believes that the obtained results represent a significant improvement of many known results in the existing literature.

Key words: Soft sets, intersection, union, difference, extended symmetric difference.

Introduction

Problems with uncertainties are a major issue in many fields such as economics, engineering, environment and so on. One of the theories that deal with uncertainties is the soft set theory which was introduced by Molodtsov in 1999 (Molodtsov, 1999) as a new mathematical tool. In the soft set theory, the problem of setting the membership function does not arise, which makes the theory easily applied to many different fields including game theory, operations research, probability theory, and measurement theory.

In the literature, different kinds of operations of soft sets are defined and used in the works on the soft set theory and its applications. Well known operations of soft sets and their properties are given by Maji et al. (Maji et al, 2003). However, some of these definitions and their properties have a few gaps, aspointed out by Ali et al. (Aliet al, 2009) and Yang (Yang, 2008). To make some modifications to the operations of soft sets and fill in these gaps, Ali et al. (Ali et al, 2009), Cagman and Enginoglu (Cagman & Enginoglu, 2010), Pei and Miao (Pei & Miao, 2005), and Sezgin and Atagun (Sezgin & Atagun,2011) have made contributions.

In 2011, Sezgin and Atagun (Sezgin & Atagun, 2011) discussed the fundamental theorems about operations of soft sets i.e; union and intersection of soft sets and other operations, see (Perović et al, 2008). In that paper, they defined union and intersection operations of soft sets both with restricted and extended conditions but defined the difference operation only with the restricted condition. In 2019, Sezgin, Ahmad and Mehmood (Sezgin et al, 2019) defined the extended difference operation.

Here in this paper, we have defined a new operation on soft sets called extended symmetric difference and also proved some of its properties. Moreover, we have also proved the interesting results which show the relationships between extended symmetric difference and other operations. The main objective of this paper is to make the soft set theory more effective and solid by enhancing the conceptual feature of operations on soft sets. This paper is one theoretical study of soft sets.

Preliminaries

In this section, we recall some basic notions in the soft set theory. Let U be an initial universe set and E_U be the set of all possible parameters under consideration with respect to U. The power set of U is denoted by $\mathcal{P}(U)$ and A is a subset of E. Usually, parameters are attributes, characteristics, or properties of objects in U. In what follows, E_U (simply denoted by E) always means the universe set of parameters with respect to U, unless otherwise specified.

Molodtsov (Molodtsov, 1999) defined the soft set in the following manner:

Definition 2.1. (Molodtsov, 1999) Let U be an initial universe set, E be a set of parameters, $\mathcal{P}(U)$ be the power set of U. A pair (F, E) is called a soft set over U, where F is a mapping of E into the set of all subsets of the set U.

In other words, a soft set over U is a parameterized family of subsets of U. For $e \in E$, $F(e)$ may be considered as the set of e-elements of the soft set (F, E) or as the set of e-approximate elements of the soft set.

Definition 2.2. (Maji et al, 2003) For two soft sets (F, A) and (G, B) over a common universe U, we say that (F, A) is a soft subset of (G, B), denoted by $(F, A) \cong (G, B)$, if it satisfies:

- $A \subset B$,
- for all $e \in A$, $F(e)$ and $G(e)$ are identical approximations.

Similarly, (F, A) is called a soft superset of (G, B) if (G, B) is a soft subset of (F, A). This relation is denoted by $(F, A) \supseteq (G, B)$.

Definition 2.3. (Maji et al, 2003) Two soft sets (F, A) and (G, B) over a common universe U are called soft equal if $(F, A) \cong (G, B)$ and $(F, A) \supseteq (G, B)$.

Definition 2.4. (Ali et al, 2009) The relative complement of a soft set (F, A) is denoted by $(F, A)^r$ and is defined by $(F, A)^r = (F^r, A)$, where $F^r: A \to P(U)$ is a mapping given by $F^r(e) = U \backslash F(e)$, for all $e \in A$.

Clearly, $(F, A)^r = \mathcal{U}_A \frown_{\mathcal{R}} (F, A)$ and $((F, A)^r)^r = (F, A)$. It is worth noting that in the above definition of complement, the parameter set of the complement $(F, A)^r$ is still the original parameter set A (Ali et al, 2009).

Definition 2.5. (Maji et al, 2003) A soft set (F, A) over U is said to be a null soft set denoted by Φ, if for all $e \in A$, $F(e) = \emptyset$ (null set).

Since some researchers are in some conflict about a null soft set due to its notation, like others (Sezgin & Atagun, 2011), so we prefer to use Φ_A instead of Φ for the null soft set of (F, A) as Ali et al. (Ali et al, 2009) used.

Definition 2.6. (Maji et al, 2003) A soft set (F, A) over U is said to be an absolute soft set denoted by $\tilde{A}$, if for all $e \in A$, $F(e) = U$.

Note that we use the notation $\mathcal{U}_A$ instead of $\tilde{A}$ as in (Ali et al, 2009) throughout this paper.

Definition 2.7. (Ali et al, 2009) Let (F,A) and (G,B) be two soft sets over a common universe U such that $A \cap B \neq \emptyset$. The restricted intersection of (F,A) and (G,B) is denoted by $(F,A) \Cap (G,B)$ and is defined as $(F,A) \Cap (G,B) = (H,C)$, where $C = A \cap B$ and for all $e \in C$, $H(e) = F(e) \cap G(e)$.

Definition 2.8. (Ali et al, 2009) Let (F,A) and (G,B) be two soft sets over a common universe U such that $A \cap B \neq \emptyset$. The restricted difference of (F,A) and (G,B) is denoted by $(F,A) \underset{\mathcal{R}}{\smile} (G,B)$ and is defined as $(F,A) \underset{\mathcal{R}}{\smile} (G,B) = (H,C)$, where $C = A \cap B$ and for all $e \in C$, $H(e) = F(e) \backslash G(e)$.

Definition 2.9. (Ali et al, 2009) Let (F,A) and (G,B) be two soft sets over a common universe U such that $A \cap B \neq \emptyset$. The restricted union of (F,A) and (G,B) is denoted by $(F,A) \underset{\mathcal{R}}{\cup} (G,B)$ and is defined as $(F,A) \underset{\mathcal{R}}{\cup} (G,B) = (H,C)$, where $C = A \cap B$ and for all $e \in C$, $H(c) = F(e) \cup G(e)$.

Definition 2.10. (Sezgin & Atagun, 2011) Let (F,A) and (G,B) be two soft sets over a common universe U such that $A \cap B \neq \emptyset$. The restricted symmetric difference of (F,A) and (G,B) is denoted by $(F,A) \underset{\mathcal{R}}{\widetilde{\Delta}} (G,B)$ and is defined as $(F,A) \underset{\mathcal{R}}{\widetilde{\Delta}} (G,B) = ((F,A) \underset{\mathcal{R}}{\cup} (G,B)) \underset{\mathcal{R}}{\smile} ((F,A) \Cap (G,B)) = (H,C)$, where $C = A \cap B$.

Definition 2.11. (Ali et al, 2009) The extended union of two soft sets (F,A) and (G,B) over a common universe U is the soft set (H,C), where $C = A \cup B$, and for all $e \in C$;

$$H(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \cup G(e) & e \in A \cap B. \end{cases}$$

We write $(F,A) \sqcup_{\mathcal{E}} (G,B) = (H,C)$.

Definition 2.12. (Ali et al, 2009) The extended intersection of two soft sets (F,A) and (G,B) over a common universe U is the soft set (H,C), where $C = A \cup B$, and for all $e \in C$;

$$H(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \cap G(e) & e \in A \cap B. \end{cases}$$

We write $(F,A) \sqcap_{\mathcal{E}} (G,B) = (H,C)$.

Definition 2.13. (Sezginet al, 2019) The extended difference of two soft sets (F, A) and (G, B) over a common universe U is the soft set (H, C), where $C = A \cup B$, and for all $e \in C$;

$$H(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \backslash G(e) & e \in A \cap B. \end{cases}$$

Thus, the relation is shown by $(F, A) \sim_{\mathcal{E}} (G, B) = (H, C)$.

Extended symmetric difference

For the fundamental properties and theorems related to operations of soft sets such as restricted union, extended union, restricted intersection, extended intersection, restricted difference, extended difference, we refer the readers to the papers Ali et al. (Ali et al, 2009), Cagman and Enginoglu (Cagman & Enginoglu, 2010), Pai and Miao (Pei & Miao, 2005), Sezgin and Atagun (Sezgin & Atagun, 2011) and Sezgin, Ahmad and Mehmood (Sezgin et al, 2019).

Now we are ready to give the definition of extended symmetric difference of soft sets and its basic properties.

Definition 3.1. The extended symmetric difference of two soft sets (F, A) and (G, B) over a common universe U is the soft set (H, C), where $C = A \cup B$, and for all $e \in C$;

$$H(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \triangle G(e) & e \in A \cap B. \end{cases}$$

Thus, the relation is shown by $(F, A) \triangle_{\mathcal{E}} (G, B) = (H, C)$.

Example 1. Let E be the universe set of parameters, A and B be the subsets of E such that

$$E = \{e_1, e_2, e_3, e_4, e_5, e_6\}, \quad A = \{e_1, e_2, e_5, e_6\}, \quad B = \{e_1, e_4, e_5, e_6\}.$$

Let (F, A) and (G, B) be two soft sets over the same universe $U = \{h_1, h_2, h_3, h_4\}$ such that

$$(F, A) = \{(e_1, \{h_1, h_3\}), (e_2, \{h_1\}), (e_5, \{h_2, h_4\}), (e_6, \{h_1, h_4\})\},$$

$$(G, B) = \{(e_1, \{h_4\}), (e_4, U), (e_5, \{h_1, h_2, h_4\}), (e_6, \{h_1, h_2\})\}.$$

Now let us determine $(F,A) \triangle_{\mathcal{E}} (G,B) = (H, A \cup B)$, where

$$H(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \triangle G(e) & e \in A \cap B, \end{cases}$$

for all $e \in A \cup B$. Since $A \backslash B = \{e_2\}$, $B \backslash A = \{e_4\}$ and $A \cap B = \{e_1, e_5, e_6\}$, then,

$$(F,A) \triangle_{\mathcal{E}} (G,B) = \{(e_2, \{h_1\}), (e_4, U), (e_1, \{h_1, h_3, h_4\}), (e_5, \{h_1\}), (e_6, \{h_2, h_4\})\}.$$

Theorem 3.2. The properties of the extended symmetric difference ($\triangle_{\mathcal{E}}$) operation

(a) $(F,A) \triangle_{\mathcal{E}} \Phi_A = (F,A)$.
(b) $(F,A) \triangle_{\mathcal{E}} (F,A) = \Phi_A$.
(c) $(F,A) \triangle_{\mathcal{E}} (G,B) = (G,B) \triangle_{\mathcal{E}} (F,A)$.
(d) $((F,A) \triangle_{\mathcal{E}} (G,B)) \triangle_{\mathcal{E}} (H,C) = (F,A) \triangle_{\mathcal{E}} ((G,B) \triangle_{\mathcal{E}} (H,C))$.
(e) $(F,A) \triangle_{\mathcal{E}} (G,B) = ((F,A) \sim_{\mathcal{E}} (G,B)) \cup_{\mathcal{R}} ((G,B) \sim_{\mathcal{E}} (F,A))$.
(f) $(F,A) \triangle_{\mathcal{E}} (G,B) = ((F,A) \sqcup_{\mathcal{E}} (G,B)) \sim_{\mathcal{E}} ((F,A) \Cap (G,B))$.
(g) $(F,A) \triangle_{\mathcal{E}} (G,B) = ((F,A) \cup_{\mathcal{R}} (G,B)) \sim_{\mathcal{E}} ((F,A) \sqcap_{\mathcal{E}} (G,B))$.

Proof.

(a) Let $\Phi_A = (S,A)$ and $(F,A) \triangle_{\mathcal{E}} \Phi_A = (F,A) \triangle_{\mathcal{E}} (S,A) = (H,A)$ where

$$H(e) = \begin{cases} F(e), & e \in A \backslash A, \\ S(e), & e \in A \backslash A, \\ F(e) \triangle S(e) & e \in A \cap A, \end{cases}$$

for all $e \in A \cup A$.

Since $S(e) = \emptyset$ for all $e \in A \cup A$, it follows that $F(e) \triangle S(e) = F(e) \triangle \emptyset = F(e)$. This means that F and H are the same mappings. This completes the proof.

(b) Let $(F,A) \triangle_{\mathcal{E}} (F,A) = \Phi_A = (H,A)$ where

$$H(e) = \begin{cases} F(e), & e \in A \backslash A, \\ F(e), & e \in A \backslash A, \\ F(e) \triangle F(e) & e \in A \cap A, \end{cases}$$

for all $e \in A \cup A$.

Hence, $F(e) \triangle F(e) = \emptyset = H(e)$. This completes the proof.

(c) Let $(F,A) \triangle_{\mathcal{E}} (G,B) = (H, A \cup B)$ where

$$H(e) = \begin{cases} F(e), & e \in A\backslash B, \\ G(e), & e \in B\backslash A, \\ F(e) \triangle G(e) & e \in A \cap B, \end{cases}$$

for all $e \in A \cup B$.

Since,

$$H(e) = \begin{cases} F(e), & e \in A\backslash B, \\ G(e), & e \in B\backslash A, \\ F(e) \triangle G(e) & e \in A \cap B, \end{cases} = \begin{cases} G(e), & e \in B\backslash A, \\ F(e), & e \in A\backslash B, \\ G(e) \triangle F(e) & e \in B \cap A, \end{cases}$$

for all $e \in A \cup B = B \cup A$, it follows that $(H, B \cup A) = (G, B) \triangle_{\mathcal{E}} (F, A)$.

(d) The proof can be illustrated by similar techniques used to prove (a), (b) and (c), and is therefore omitted.

(e) For the left-hand side of the property, let $(F, A) \triangle_{\mathcal{E}} (G, B) = (H, A \cup B)$, where

$$H(e) = \begin{cases} F(e), & e \in A\backslash B, \\ G(e), & e \in B\backslash A, \\ F(e) \triangle G(e) & e \in A \cap B, \end{cases}$$

for all $e \in A \cup B$.

For the right-hand side of the property, let $(F, A) \sim_{\mathcal{E}} (G, B) = (I, A \cup B)$, where

$$I(e) = \begin{cases} F(e), & e \in A\backslash B, \\ G(e), & e \in B\backslash A, \\ F(e)\backslash G(e) & e \in A \cap B, \end{cases}$$

for all $e \in A \cup B$. Suppose that $(G, B) \sim_{\mathcal{E}} (F, A) = (J, A \cup B)$, where

$$J(e) = \begin{cases} G(e), & e \in B\backslash A, \\ F(e), & e \in A\backslash B, \\ G(e)\backslash F(e), & e \in A \cap B. \end{cases}$$

Assume that, $(I, A \cup B) \cup_{\mathcal{R}} (J, A \cup B) = (K, (A \cup B) \cap (A \cup B))$, where $K(e) = I(e) \cup J(e)$ for all $e \in (A \cup B) \cap (A \cup B) = A \cup B$.

Now, we have

$$K(e) = \begin{cases} I(e) \cup J(e), & e \in A\backslash B, \\ I(e) \cup J(e), & e \in B\backslash A, \\ I(e) \cup J(e), & e \in A \cap B, \end{cases}$$

$$= \begin{cases} F(e) \cup F(e), & e \in A\backslash B, \\ G(e) \cup G(e), & e \in B\backslash A, \\ (F(e)\backslash G(e)) \cup (G(e)\backslash F(e)), & e \in A \cap B, \end{cases}$$

for all $e \in (A \cup B) \cup (A \cup B) = A \cup B$. It shows that H and K are the identical mapping when we are assuming the attributes of operations about the set theory. Hence the proof is completed.

(f) For the left-hand side of the property, let $(F, A) \triangle_{\mathcal{E}} (G, B) = (H, A \cup B)$, where

$$H(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \triangle G(e), & e \in A \cap B, \end{cases}$$

for all $e \in A \cup B$. For the right-hand side of the property, let $(F, A) \sqcup_{\mathcal{E}} (G, B) = (I, A \cup B)$, where

$$I(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \cup G(e), & e \in A \cap B, \end{cases}$$

for all $e \in A \cup B$. And suppose that $(G, B) \Cap (F, A) = (J, A \cap B)$, where $J(e) = A(e) \cap B(e)$ for all $e \in A \cap B$.

Assume that, $(I, A \cup B) \sim_{\mathcal{E}} (J, A \cap B) = (K, (A \cup B) \cup (A \cap B))$, where

$$K(e) = \begin{cases} I(e), & e \in (A \cup B) \backslash (A \cap B), \\ J(e), & e \in (A \cap B) \backslash (A \cup B), \\ I(e) \bigcup J(e), & e \in (A \cup B) \cap (A \cap B), \end{cases} = \begin{cases} I(e), & e \in A \backslash B, \\ I(e), & e \in B \backslash A, \\ J(e), & e \in \emptyset, \\ I(e) \bigcup J(e), & e \in A \cap B, \end{cases}$$

i.e.

$$K(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ (F(e) \cup G(e)) \backslash (F(e) \cap G(e)), & e \in A \cap B, \end{cases}$$

$$= \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \triangle G(e), & e \in A \cap B, \end{cases}$$

for all $e \in (A \cup B) \cup (A \cap B) = A \cup B$. This leads that H and K are the identical mapping. Hence this completes the proof.

(g) For the left-hand side of the property, let $(F, A) \triangle_{\mathcal{E}} (G, B) = (H, A \cup B)$, where

$$H(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \triangle G(e), & e \in A \cap B, \end{cases}$$

for all $e \in A \cup B$.

For the right-hand side of the property, let $(G, B) \cup_{\mathcal{R}} (F, A) = (I, A \cap B)$, where $I(e) = A(e) \cup B(e)$ for all $e \in A \cap B$.

And suppose that $(F,A) \sqcap_{\mathcal{E}} (G,B) = (J, A \cup B)$, where

$$J(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \cap G(e), & e \in A \cap B, \end{cases}$$

for all $e \in A \cup B$.

Assume that, $(I, A \cap B) \sim_{\mathcal{E}} (J, A \cup B) = (K, (A \cap B) \cup (A \cup B))$, where

$$K(e) = \begin{cases} I(e), & e \in (A \cap B) \backslash (A \cup B), \\ J(e), & e \in (A \cup B) \backslash (A \cap B), \\ I(e) \bigcup J(e), & e \in (A \cap B) \cap (A \cup B), \end{cases} = \begin{cases} I(e), & e \in \emptyset, \\ J(e), & e \in A \backslash B, \\ J(e), & e \in B \backslash A, \\ I(e) \bigcup J(e), & e \in A \cap B, \end{cases}$$

i.e.

$$K(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ (F(e) \cup G(e)) \backslash (F(e) \cap G(e)), & e \in A \cap B, \end{cases}$$

$$= \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \triangle G(e), & e \in A \cap B, \end{cases}$$

for all $e \in (A \cup B) \cup (A \cap B) = A \cup B$.

This leads that H and K are the identical mapping.

Hence this completes the proof.

Now we will illustrate Theorem 3.2.(parts (e) and (f)) with a corresponding example.

Example 2. Let E be the universe set of parameters, A and B be the subsets of E such that

$E = \{e_1, e_2, e_3, e_4, e_5, e_6\}, \quad A = \{e_1, e_2, e_5, e_6\}, \quad B = \{e_1, e_4, e_5, e_6\}$.

Let (F,A) and (G,B) be two soft sets over the same universe $U = \{h_1, h_2, h_3, h_4\}$ such that

$$(F,A) = \{(e_1, \{h_1, h_3\}), (e_2, \{h_1\}), (e_5, \{h_2, h_4\}), (e_6, \{h_1, h_4\})\},$$

$$(G,B) = \{(e_1, \{h_4\}), (e_4, U), (e_5, \{h_1, h_2, h_4\}), (e_6, \{h_1, h_2\})\}.$$

Now let us determine $(F,A) \triangle_{\mathcal{E}} (G,B) = (H, A \cup B)$, where

$$H(e) = \begin{cases} F(e), & e \in A \backslash B, \\ G(e), & e \in B \backslash A, \\ F(e) \triangle G(e) & e \in A \cap B, \end{cases}$$

for all $e \in A \cup B$.

Since $A \backslash B = \{e_2\}$, $B \backslash A = \{e_4\}$ and $A \cap B = \{e_1, e_5, e_6\}$, then,

$$(F,A)\ \triangle_{\mathcal{E}}\ (G,B)$$
$$= \{(e_2,\{h_1\}),(e_4,U),(e_1,\{h_1,h_3,h_4\}),(e_5,\{h_1\}),(e_6,\{h_2,h_4\})\}.$$

On the other side, we can easily determine that it is

$$((F,A)\sim_{\mathcal{E}}(G,B)) = \{(e_2,\{h_1\}),(e_4,U),(e_1,\{h_1,h_3\}),(e_5,\emptyset\}),(e_6,\{h_4\})\},$$

and

$$((G,B)\sim_{\mathcal{E}}(F,A)) = \{(e_2,\{h_1\}),(e_4,U),(e_1,\{h_4\}),(e_5,\{h_1\}),(e_6,\{h_4\})\}.$$

Based on Definition 2.9. we have that

$$((F,A)\sim_{\mathcal{E}}(G,B))\cup_{\mathcal{R}}((G,B)\sim_{\mathcal{E}}(F,A))$$
$$= \{(e_2,\{h_1\}),(e_4,U),(e_1,\{h_1,h_3,h_4\}),(e_5,\{h_1\}),(e_6,\{h_2,h_4\})\}.$$

Therefore, $(F,A)\ \triangle_{\mathcal{E}}\ (G,B) = ((F,A)\sim_{\mathcal{E}}(G,B))\cup_{\mathcal{R}}((G,B)\sim_{\mathcal{E}}(F,A))$.

Similarly, we can easily determine that it is

$$((F,A)\sqcup_{\mathcal{E}}(G,B))$$
$$= \{(e_2,\{h_1\}),(e_4,U),(e_1,\{h_1,h_3,h_4\}),(e_5,\{h_1,h_2,h_4\}),(e_6,\{h_1,h_2,h_4\})\},$$

and

$$((F,A)\Cap(G,B)) = \{(e_1,\emptyset),(e_5,\{h_2,h_4\}),(e_6,\{h_1\})\}.$$

Based on Definition 2.13. we have that

$$((F,A)\sqcup_{\mathcal{E}}(G,B))\sim_{\mathcal{E}}((F,A)\Cap(G,B))$$
$$= \{(e_2,\{h_1\}),(e_4,U),(e_1,\{h_1,h_3,h_4\}),(e_5,\{h_1\}),(e_6,\{h_2,h_4\})\}.$$

Therefore, $(F,A)\ \triangle_{\mathcal{E}}\ (G,B) = ((F,A)\sqcup_{\mathcal{E}}(G,B))\sim_{\mathcal{E}}((F,A)\Cap(G,B))$.

Conclusion

In this paper, we have illustrated a brief analytical review of operations of soft sets. We have defined the extended symmetric difference of soft sets and also proved some of its properties. Moreover, we have shown the relationship between extended symmetric difference and some other operations of soft sets.

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НОВАЯ ОПЕРАЦИЯ НАД МЯГКИМИМНОЖЕСТВАМИ: РАСШИРЕННАЯ СИММЕТРИЧЕСКАЯ РАЗНОСТЬ МЯГКИХ МНОЖЕСТВ

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РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА:
27.17.00 Алгебра;
27.17.21 Структуры
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Д.А. Молодцов представил концепцию мягких множеств в качестве нового математического инструмента для решения задач, содержащих неопределенности. В литературе определены различные виды операций над мягкими множествами, которые используются в теории и на практике.

Методы: Данная статья основана на исследовании Сезгина, Ахмада и Мехмуда «Новая операция над мягкими множествами: расширенная разность мягких множеств» [Journal of New Theory 27 (2019) 33-42].

Результаты: В данной статье представлена новая операция над мягкими множествами, называемая расширенной

симметрической разностью, а также результаты исследования взаимосвязи между расширенной симметрической разностью и ограниченной симметрической разностью и некоторыми другими операциями мягких множеств.

Выводы: Автор считает, что полученные им результаты представляют значительный вклад в исследуюмую область.

Ключевые слова: мягкие множества, пересечение, объединение, разность, расширенная симметрическая разность.

НОВА ОПЕРАЦИЈА СОФТ СКУПОВА: ЊИХОВА ПРОШИРЕНА СИМЕТРИЧНА РАЗЛИКА

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ОБЛАСТ: математика
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Молодсов је представио концепт софт скупа као ново математичко средство за решавање проблема у којима се јавља неизвесност. У литератури су различите врсте операција софт скупова дефинисане и коришћене у теорији и различитим облицима примена.

Методе: Овај рад заснован је на раду „Нова операција софт скупова: проширена разлика софт скупова" аутора Сезгина, Ахмада и Мехмуда [Journal of New Theory 27 (2019) 33-42].

Резултати: Дефинисана је нова операција софт скупова, која се назива проширена симетрична разлика. Истражена је веза између проширене и ограничене симетричне разлике и неких других операција софт скупова.

Закључак: Аутор верује да добијени резултати представљају значајан допринос досадашњим познатим резултатима.

Кључне речи: софт скупови, пресек, унија, разлика, проширена симетрична разлика.

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MULTIPLE-CRITERIA MODEL FOR OPTIMAL ANTI TANK GROUND MISSILE WEAPON SYSTEM PROCUREMENT

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FIELD: Mathematics, Logistics
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Abstract:

Introduction: Anti Tank Ground Missiles (ATGMs) are one of the most efficient weapon systems to counter armored and mechanized units. Procurement of these weapons is imperative for armed forces of any country. Adequate evaluation and choice of an efficient ATGM system is a very important factor which affects operational capabilities of armed forces. The purpose of this paper is to present that multi criteria methods can be a useful tool for optimal procurement of ATGMs for armed forces.

Methods: The implementation of the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and the MABAC (Multi Attributive Border Approximation Area Comparison) multi criteria methods will be proposed for decision makers to solve the problem of ATGM procurement. In this paper, four models of ATGMs will be proposed as possible solutions. These ATGMs will be presented as alternatives A1, A2, A3 and A4.

Results: The implementation of the methods in this paper has led to the conclusion that the alternative A2 has the highest value and therefore the best course of action for decision makers is to chose procurement of this model of ATGMs.

Conclusion: The conclusion is that the mathematical models of multi-criteria decision making presented in this paper unequivocally point to the alternative with the best characteristics, thus presenting extremely useful tools for decision makers.

Key words: TOPSIS, MABAC, weapon system procurement, multi-criteria decision making.

Introduction

Anti Tank Ground Missiles (ATGMs) represent one of the most efficient weapon systems present in armed forces globally. The primary purpose of these systems is anti armor defense, as well as partial anti air defense against low flying targets (helicopters and unmanned aerial vehicles). High hit probability and long range of engagement place these systems among the most deadly battlefield threats to armor units.

Regarding the fact that procurement of ATGMs represents one of the imperatives for equipping armed forces, the most optimal selection of ATGMs is one of the most challenging tasks for state decision makers, i.e. officials of the Defense Ministry.

Operational research as a basic management discipline based on mathematical formalism, with multi criteria methods as fundamentals for a decision making process, represents a solution for the ATGM procurement problem.

The objective of this paper is to present the capabilities of the multi criteria model as a comprehensive method for a decision making process where there is a need to select the most optimal solution.

In order to represent the complexity of the ATGM procurement problem, the first part of this paper will give a short history of ATGM development as well as the ATGM basic tactical and technical characteristics. The tactical and technical characteristics of ATGMs represent just a small portion of criteria included in the decision making process. All criteria which are in accordance with the adopted national defense doctrine must be included. Also, one of the crucial criteria is the cost-effectiveness criterion.

The ATGMs which will be described in this paper are fictional. Their specifications are approximate to real weapon systems in usage. The data for ATGMs are collected by accessing available reference documents primarily by the examination of official manufacturers' weapons specifications. As we already mentioned, the presented data will be partially changed in order to avoid similarity with actual weapon systems.

In the second part of this paper, the TOPSIS & MABAC multi-criteria methods will be explained. These methods will be employed as a decision making tool for the ATGM procurement.

The motivation for selecting the TOPSIS and MABAC methods is justified by fact that these methods are comprehensive and represent one of the latest and most advanced scientific methods in the decision-making process.

ATGM development history and basic characteristics

The ATGM development started at the end of WWII in Nazi Germany. Primarily, it was the Ruhrstahl X-7(Rotkäppchen –„Little Red Riding Hood“). The guidance method was manual, meaning that the operator was guiding a missile by the guidance panel with the joystick. After a missile is launched, the operator follows the missile and in the same time the operator follows the target (e.g. armored vehicle). With the command stick, the operator corrects the flight of the missile until it hits the target. The explained method is described as “Three-point guidance method” (operator’s eye, missile, target) or, in Western literature, as MCLOS (Manual Command to Line of Sight). A typical example of this ATGM generation is the 9M14 Malyutka (Russian: Малютка; "Little one", NATO reporting name: AT-3 Sagger). The main characteristic of the first generation of ATGMs was long-lasting and complex training. The combat effectiveness of these ATGMs was approximately 25% during the Arab-Israel conflict in 1973.

Figure 1 – 9M14 Malyutka (AT-3 Sagger), (Military-Today, 2021)
Рис. 1 – 9М14 «Малютка» (Military -Today, 2021)
Слика 1 – 9М14 „Малутка” (Military -Today, 2021)

The two-point guidance method (operator’s eye and target) is used in the second generation of ATGMs. After a missile is launched, this guidance method enables the operator to only constantly track a target with crosshairs (without following the missile flight), while the automatic system (the guidance block) processes and sends appropriate commands

to the missile and therefore guides the missile to the target. The communication with the guidance block is conducted by wire or by radio waves. Typical examples of this generation ATGMs are: MILAN, 9K111 „FAGOT“(NATO reporting: AT-4 Spigot), BGM-71 TOW, and „BUMBAR“ – developed and produced in Serbia. The examples are given in Figure 2.

Figure 2 – Second generation ATGMs: MILAN, BGM-71 TOW (upper section); 9K111 „FAGOT“ and „BUMBAR“(lower section)
Рис. 2 – ПТУР второго поколения: MILAN, BGM-71 TOW (верхний ряд); 9K111 «ФАГОТ» и «БУМБАР» (нижний ряд)
Слика 2 – ПОВР друге генерације: MILAN, BGM-71 TOW (горњи ред); „ФАГОТ” и „БУМБАР” (доњи ред)

The two-point guidance method is also employed on ATGMs guided by a focused beam (usually a laser beam) where a missile itself has an installed system which provides “riding a missile on a beam” and therefore there is no need for wire communication with the launching platform. The typical examples of this generation ATGMs are the 9M133 Kornet and the 9M119 Svir/Refleks (booth manufactured in Russia). The hit probability of the second generation of ATGMs is about 90%.

The third generation of ATGMs completely employs an automated guidance system. In Western literature, this system is designated as a "Fire and Forget" system. The operator selects a target and after launching the automatic system tracks the target and guides the missile to the target. The typical example of the third generation of ATGMs is the 9M133M Kornet-M. The automated system conducts the target tracking and focuses the laser beam to a target, which is used to guide a missile. This ATGM presents an improved version of the second generation of the 9M133 ATGM. The launching platform is capable of tracking two targets simultaneously. Besides anti-tank engagement, the system is intended for low altitude anti-aircraft defense (e.g. against unmanned aerial vehicles). The 9M133M Kornet-M ATGM is presented in Figure 3. The photo represents a Kornet D variant which is capable of carrying 8 missiles (with additional 8 in reserve) on the GAZ 2975 all-terrain vehicle.

Figure 3 –9M133M Kornet-M ATGM on the Kornet D platform
Рис. 3 – ПТУР 9М133М «КОРНЕТ-М» на платформе «КОРНЕТ Д»
Слика 3 – ПОВР 9М133М „КОРНЕТ – М" на „КОРНЕТ Д" платформи

The FGM-148 Javelin ATGM, manufactured by Raytheon Technologies, USA, represents one of the most sophisticated combat systems. One of the distinctive characteristics featured in this combat system is ability to attack the target from above where the upper armor is

much thinner than the frontal armor, thus significantly improving target destruction probability.

This missile employs a section designated as a Seeker section. The seeker section consists of an imaging infrared system (I2R) and a contact fuse for warhead detonation. The I2R system provides the Fire and Forget capability. During the missile flight, the I2R system tracks a target and provides data to the electronic unit installed in the missile. Figures 4 and 5 show the target acquisition. After locating a target, the operator turns on the narrow field of view which engages track gates and crosshairs projected in intervals, indicating that the seeker is detecting target thermal reflection, or so called “target lock”.

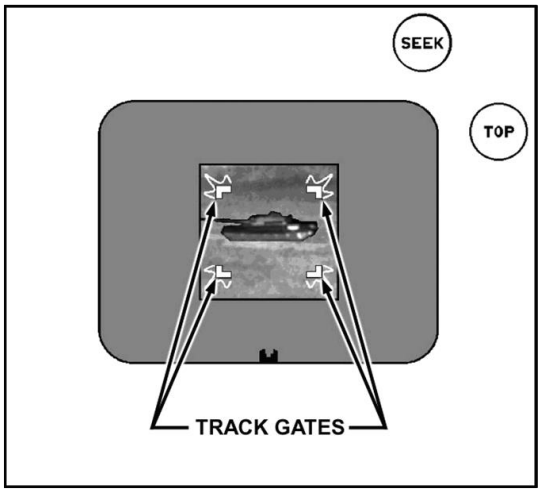

Figure 4 – Target thermal reflection detection – “Target lock”
Рис. 4 – Тепловое обнаружение ИК отражения- «Закрытая мишень»
Слика 4 – Детектовање инфрацрвеног одраза – „закључавање” циља

When the strongest thermal reflection is detected, the track gates and the crosshairs become solid, which is the indication that the target is “locked”, i.e. the firing conditions are fulfilled and the system is ready to launch a missile (Figure 5).

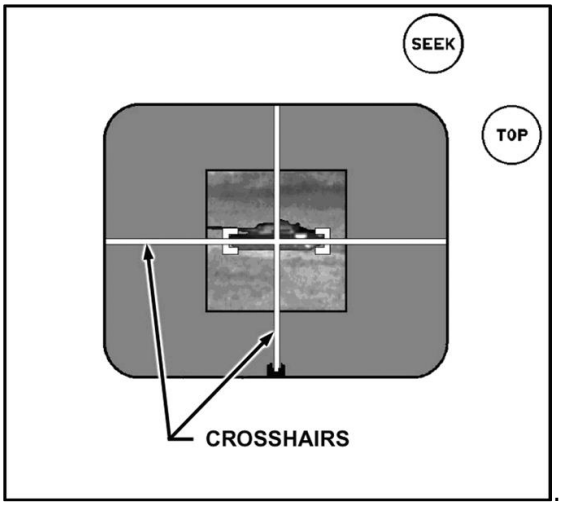

Figure 5 – Target "Locked" firing conditions fulfilled; system ready to launch a missile
Рис. 5 – Условия стрельбы по «Закрытой мишени» выполнены
Слика 5 – Циљ „закључан" – услови за гађање испуњени

ATGMs are equipped with a warhead which destroys a target with an explosion cumulative effect[1]. A cumulative explosion effect represents focusing energy to a surface smaller than the outer surface of the explosive charge. Energy accumulation is created by a proper shape of the explosive charge. If the outer surface is shaped with a cone cavity (so called cumulative cavity), detonation products are focused in the center of the cavity. In that manner, energy accumulation is created on a smaller surface and therefore the effect of a larger magnitude is created.

The coating of the cumulative cavity also increases penetration capability. For the coating, the most used metal is copper, but steel can also be used as well as sintered metals. Figure 6 shows the formation of a cumulative beam while a cumulative beam formation radiograph is presented in Figure 7.

[1] In Western literature, the term *shaped-charge* is used.

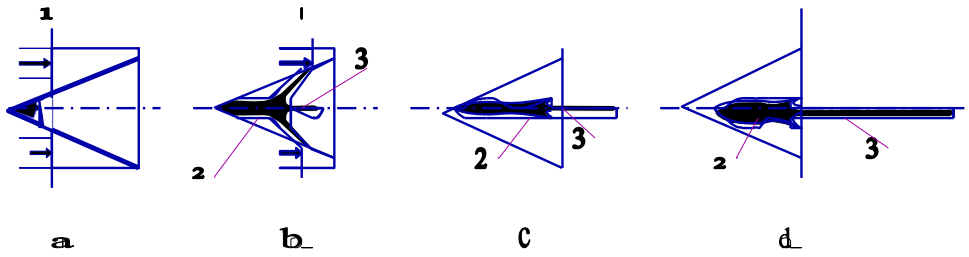

Figure 6 – Forming of a cumulative beam (1 – detonation wave; 2 – secondary beam; 3 – primary beam)
Рис. 6 – Формирование кумулятивного снаряда (1 − детонационная волна; 2 − вторичная струя; 3 − первичная струя)
Слика 6 – Формирање кумулативног млаза (1 – детонациони талас; 2 – секундарни млаз; 3 – примарни млаз)

Figure 7 – Cumulative beam formation radiograph
Рис. 7 – Рентгенограмма кумулятивного формирования струи
Слика 7 – Рендгенографски снимак кумулативног млаза у формирању

Modern ATGMs employ a so-called tandem-cumulative warhead[2] which is capable of forming two cumulative beams following each other. These beams are formed by two separated cumulative cavities. The purpose of the primary beam is to activate Explosive Reactive Armor

[2] In Western literature, the term *tandem-charge* is used.

(ERA)[3], and then the secondary beam penetrates the main armor. Modern third generation ATGMs penetrate more than 1,300 mm of homogenous armor behind ERA.

One of important characteristics of ATGMs is missile velocity. ATGM velocity is usually measured in meters per second (m/s) and it is ranged from 120 m/s (First generation ATGM e.g. 9M14 Malyutka) up to 300 m/s (Third generation ATGM e.g. ATGM 9M133M Kornet-M). It is evident that missile velocity is an important characteristic considering battlefield multiple targets engagement. From the previous example, it can be noticed that the third generation of ATGMs has the velocity almost twice as high as that of the first generation. Let us have an example when the operator locates two targets at a range of 2400 meters. For the guidance of the first generation of ATGMs, the operator needs approximately 20 seconds. For the guidance of the third generation of ATGMs, the operator needs approximately 8 seconds. This means that the operator armed with a third generation ATGM has enough time to destroy two targets, unlike the operator armed with a first generation ATGM.

The ATGM range of engagement is also an important characteristic. The ATGM range of engagement is form 3000 meters for the first generation ATGMs (e.g. 9M14 Malyutka) up to 8000 meters for the third generation ATGMs (e.g. 9M133M Kornet-M).

Regarding ATGM procurement for armed forces, the price of ATGMs is a factor which must be considered in conjunction with economic capabilities of the armed forces in question. Also, the ATGM weight must be considered in conjunction with armed forces transportation capabilities, as well as with the mobility of units armed with ATGMs.

In modern armed conflicts, electronic warfare (EW) is employed through system jamming, so electronic counter-countermeasures (ECCM) must be implemented, which for ATGMs can be expressed as jamming resistance. Besides jamming resistance, reliability is demanded for weapon systems.

Based on the previously mentioned ATGM development history and the presented tactical & technical characteristics, the following criteria should be taken into account when procuring ATGMs:

- Engagement range,
- Hit probability,
- Weight,
- Price,

[3] Explosive Reactive Armor consists of explosive plates whose purpose is to disrupt a cumulative beam thus preventing armor penetration.

- Training simplicity,
- Reliability,
- Jamming resistance, and
- Missile velocity.

Multiple-criteria decision process

In the previous chapter, the problem of ATGM procurement for armed forces has been presented. Finding an optimal solution, i.e. the decision making process and the selection of the “best” alternative, is based on multiple criteria and on series of limitations. The concerned criteria can be, by their nature, very diverse, and expressed in different units of measurement, from currency followed by physical units of measurement to subjective assumptions measured by a scale formed for a problem in question. Therefore, a final, unique solution cannot be determined without the participation of a decision maker. A decision maker must decide on a particular solution. The solution adopted by the decision maker is designated as the best or the most preferred solution. The task of multiple-criteria decision process is to provide assistance to the decision maker to select the best solution in the given conditions. Therefore, efforts made for solving multiple-criteria problems are designated as a multiple-criteria decision analysis.

The problems of multi-criteria optimization are characterized by:

- Presence of multiple criteria (objective function, criteria function) for decision making,
- Presence of multiple alternatives (solutions) for the selection,
- Presence of a designing process or solution selection,
- Presence of conflicts between the criteria, which is the most common case in real life problems,
- Incomparable units of measurement for different criteria, and
- Selection process of one final solution, which can be presented as a design of an action (alternative), or a selection of one particular action from the previously defined convolution of final actions.

There are many multiple-criteria decision process methods which have common aspects. The characteristic terms which occur in these methods are:

- Alternatives – represent selections of different actions which are available for a decision maker. The convolution of alternatives

implies limited convolution, ranging from a few to a few hundreds. It is assumed that alternatives are verified, prioritized and in some cases ranked.

- Multiple attributes – different designations of attributes are “objectives” or “decision criteria” and represent different dimensions for which alternatives can be observed.
- Criteria conflict – different criteria represent different dimensions which can be in conflict.
- Incomparable units of measurement – different criteria can be linked with different units of measurement.
- Decision magnitude – most methods of the multiple-criteria decision process demand assignment of the weight criteria in accordance with their importance. Usually, these weights are normalized so that their sum equals one.
- Decision matrix – the multiple-criteria decision process can be represented in the form of a matrix. The decision matrix (*mxn*) is a matrix in which the element a_{ij} represents the characteristics of the alternative A_i where *(i=1,2,…, m)*, when the alternative A_i is valued in accordance with the decision criteria C_j *(j=1, 2, …, n).* Also, it is presumed that the decision maker has assigned the weight criterion w_j *(j=1, 2, …, n)*.

Multiple-criteria decision methods are employed in multiple disciplines and can be used in problem solving for any decision making process with multiple criteria. We well cite only a fraction of areas in which multiple criteria decision methods are employed:

- application in cargo distribution companies (Adar& Delice, 2019)
- healthcare waste treatment technology selection (Adar& Delice, 2020)
- menu evaluation (Arsić et al, 2019)
- decision making: applications in management and engineering (Božanić et al, 2020b)
- evaluating sustainable transportation systems (Muhammad et al, 2021)
- sustainable city logistics planning (Alosta et al, 2021)

- evaluation of the performance of deposit banks (Ayçin & Orçun, 2019)
- supplier selection (case study in pharmaceutical supplying in Libya) (Badi & Ballem, 2018)
- efficiency of the social media (Bobar et al, 2020)
- supporting decision making in the army (Božanić et al, 2020a)
- evaluating locations for river crossing (Božanić & Pamučar, 2010)
- ranking potential locations for preparing laying-up positions (Božanić et al, 2016a)
- selection of the location for construction, reconstruction and repair of flood defense facilities (Božanić et al, 2019a)
- selection of a location for the construction of a single-span bailey bridge (Božanić et al, 2019b)
- proposal for an optimal location of emergency operation centers (Di Matteo et al, 2016)
- support a decision making process of force deployment in a defense operation (Božanić et al, 2016b)
- support a decision making process of force deployment in a defense operation (Pamučar et al, 2016)
- selecting a location for wind farms (Gigović et al, 2017)
- selection of the railroad container terminal (Milosavljević et al, 2018)
- selection of transport and handling resources in logistics centers (Pamučar & Ćirović, 2015)
- optimal off-road vehicle selection for passenger transportation (Pamučar & Savin, 2020)
- sustainable selection of a location for the development of a multimodal logistics centre (Pamucar et al, 2018b)
- evaluating the work of advisors in the transport of hazardous goods (Pamučar et al, 2019)
- evaluation of level crossings (Pamučar et al, 2018a)
- selecting an airport ground access mode (Pamucar et al, 2020)
- survey on military operations of the fuzzy set theory and its applications (Deveci et al, 2020a)

- comparison of two fuzzy multi criteria decision methods for selecting a potential airport location (Belbag et al, 2013)
- comparative analysis of fuzzy multi-criteria decision making for selecting a location for a textile plant in Turkey (Demirel et al, 2016)
- wind farms site selection (Deveci et al, 2020b) and (Deveci et al, 2021).

Description of multiple-criteria decision methods used in the decision making process for the problem in question

The methods of multiple-criteria decision making which will be used for finding the best solution are the TOPSIS и MABAC methods:

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was developed by Hwang and Joon. This method implies ranking alternatives by multiple criteria based on the comparison of distances from the ideal solution and the negative ideal solution. The ideal solution minimizes the cost based criteria and maximizes the benefit type criteria, while for the negative ideal solution the opposite rule is implied.

The TOPSIS consists of six steps. Prior to the presentation of these steps, the terms to be used will be defined. In this method, the decision matrix *R* is used, where every alternative is matched by one row and every column is matched by one criterion. The element r_g represents the alternative performance A_i related to the criterionC_j. For *m* criteria (C_1,C_2...,C_m) and *n* alternatives (A_1,A_2...,A_n), the matrix *R* has the following form:

$$R = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \dots\dots & \dots & & \\ r_{n1} & r_{n2} & \dots & r_{mn} \end{bmatrix}$$

and the values (w_1,w_2...,w_m) represent the weight values of the criteria. The weight of the criteria must be in compliance with the condition$\sum_{i=1}^{n} w_i$.

Step 1 Decision matrix values normalization. In the majority of multiple-criteria decision methods, the first step is decision matrix elements normalization in order to get a matrix in which all elements are

un-dimensional values. In the TOPSIS method, vector normalization is applied, represented by expressions (2.1) and (2.2).

$$x_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^2}}, \text{ for the "benefit" type criteria} \quad (2.1)$$

After normalization implementation, the *X* matrix is obtained in which all elements are normalized and are in the interval $[0, 1]$.

$$X = \begin{matrix} A_1 \\ A_2 \\ \cdot \\ A_n \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{mn} \end{bmatrix} \quad (2.2)$$

Step 2 Multiplication of the *X* matrix normalized values with the weight criteria coefficients.

$$v_{ij} = x_{ij} \cdot w_j \; ; j = 1,2 \ldots, m \quad (2.3)$$

With relation (2.3), the elements of the weight normalized matrix $V = (v_g)$, are obtained, where every v_g is a product of the normalized alternative performance and the appropriate criterion coefficient.

$$V = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1m} \\ v_{21} & v_{22} & \cdots & v_{2m} \\ \cdots & \cdots & \cdots & \\ v_{n1} & v_{n2} & \cdots & v_{mn} \end{bmatrix} = \begin{matrix} A_1 \\ A_2 \\ \cdot \\ A_n \end{matrix} \begin{bmatrix} w_1 \cdot & x_{11}w_2 \cdot & x_{12} \cdots w_m \cdot & x_{1m} \\ w_2 \cdot & x_{11}w_2 \cdot & x_{22} \cdots w_m \cdot & x_{2m} \\ & \cdots \cdots \cdots & \cdots \cdots \cdots & \\ w_1 \cdot & x_{n1}w_2 \cdot & x_{n2} \cdots w_m \cdot & x_{nm} \end{bmatrix} \quad (2.4)$$

Step 3. Determination of ideal solutions. The ideal solution A^* and the negative ideal solution are obtained by the following relations:

$$A^* = \left\{\left(\max v_{ij} \,\middle|\, j \in G\right), \left(\min v_g \,\middle|\, j \in G'\right), i = 1, \ldots, n\right\} = \{v_1^*, v_2^*, \ldots, v_m^*\} \quad (2.5)$$

$$A'' = \left\{\left(\min v_{ij} \,\middle|\, j \in G\right), \left(\max v_g \,\middle|\, j \in G'\right), i = 1, \ldots, n\right\} = \{v_1^-, v_2^-, \ldots, v_m^-\} \quad (2.6)$$

where:

$G = \{j = 1,2, \ldots m | japertaintocriteriawhicharemaximized\}$

$G' = \{j = 1,2, \ldots m | japertaintocriteriawhichareminimized\}$

The best alternatives are those which have the biggest v_g relative to the criteria which are maximized and the smallest v_g relative to the criteria which are minimized. A^* indicates the best alternative (the ideal solution), and, using the same logic, A'' indicates the negative ideal solution.

Step 4 Determination of alternative distances from the ideal solution. In this step, using the following relations:

$$S_i^* = \sum_{j=1}^{m}\left(v_{ij} - v_j^*\right)^2, i = 1, \dots, n \quad (2.7)$$

$$S_i^- = \sum_{j=1}^{m}\left(v_{ij} - v_j^-\right)^2, i = 1, \dots, n \quad (2.8)$$

n dimensional Euclid distances are calculated of all alternative distances from the ideal solution and from the negative ideal solution.

Step 5 Determination of relative alternatives proximity to the ideal solution. For each alternative, relative distance is determined:

$$Q_i^* = \frac{S_i^-}{S_i^* - S_i^-}, \qquad i = 1, \dots, n \quad (2.9)$$

where $0 \leq Q_i^* \leq 1$. The alternative A_i is closer to the ideal solution if Q_i^* is closer to the value of 1, or, which is the same, if S_i^* is closer to the value of 0.

Step 6 Ranking of alternatives. The alternatives are ranked by the descending values Q_i^*. The best alternative is the alternative with the highest Q_i^* value and vice versa.

The MABAC (Multi-Attributive Border Approximation area Comparison) represents one of recent date methods. The MABAC method was developed by Dragan Pamucar, PhD, University of Defence in Belgrade, Military Academy, Department of Logistics. Up to this date, this method has found wide application and modifications in multiple-criteria problem solving. The MABAC method basic setting is to define every criterion function distance from the border approximate area. The MABAC method consists of 6 steps:

Step 1: Base matrix forming(X). In the first step, the evaluation of m alternatives per n criteria is performed. The alternatives are presented by vectors $A = (x_{ij}, x_{i2}, \dots, x_m)$ where the value $x_g$is the value of the i alternative per the i criterion($i = 1,2, \dots, m; j = 1,2, \dots, n$).

$$X = \begin{matrix} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \end{matrix} \tag{2.10}$$

and where m represents an alternative number while n is the total number of criteria.

Step 2 Elements normalization of the base matrix$x$.

$$X = \begin{matrix} \\ A_1 \\ A_2 \\ \dots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix} \\ \begin{bmatrix} t_{11} & t_{12} & \dots & t_{1n} \\ t_{21} & t_{22} & \dots & t_{1n} \\ \dots & \dots & \dots & \dots \\ t_{m1} & t_{m2} & \dots & t_{mn} \end{bmatrix} \end{matrix} \tag{2.11}$$

The elements of the normalized matrix N are determined by the expression:

a) For the "benefit" type criteria (higher value desired)

$$t_g = \frac{x_g - x_i^-}{x_i^+ - x_i^+} \tag{2.12}$$

b) For the "cost" type criteria (lower value desired)

$$t_g = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+} \tag{2.13}$$

where $x_{ij}, x_i^+ and x_i^-$ represent the elements of the base matrix(X), where $x_i^+ and x_i^-$ are defined as:

$x_i^+ = max(x_1, x_2, \dots, x_m)$ and represents the maximum values of a considered criterion per alternatives.

$x_i^+ = min(x_1, x_2, \dots, x_m)$ and represents the minimum values of a considered criterion per alternatives.

Step 3 Aggravated matrix(V) elements calculation. The elements of the aggravated matrix (V) are calculated by expression (2.14):

$$v_g = w_i \cdot t_g + w_i \tag{2.14}$$

where (t_g) represents the elements of the normalized matrix$(N), w_i$, represents weight criteria coefficients. By the application of expression (2.14), the aggravated matrix$(V)$is obtained:

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

where n represents the total number of criteria and m represents the total number of alternatives.

Step 4 Determination of the border approximate area(G). The border approximate area (BAA) is determinated by expression (2.15):

$$g = \left(\prod_{j=1}^{m} V_{ij}\right)^{\frac{1}{m}} \tag{2.15}$$

where v_{ij} represents the elements of the aggravated matrix (V) and m represents the total number of alternatives. After the calculation of the values g_i per the border approximate area(G) criterion, the matrix is formed with a format $nx\,1$ (n represents the total number of criteria by which the selection of the offered alternatives is performed).

$$G = \begin{matrix} C_1 & C_2 & \dots & C_n \end{matrix} \\ \begin{bmatrix} g_1 & g_2 & \cdots & g_n \end{bmatrix} \tag{2.16}$$

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

$$V = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & \cdots & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \quad (2.17)$$

The alternative distance from the border approximate area (q_{ij}) is determinated as divergence of the elements of the aggravated matrix (V) and the values of the border approximate area(G):

$$Q = V - G = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} - [g_1 \quad g_2 \quad \cdots \quad g_n] \quad (2.18)$$

$$V = \begin{bmatrix} v_{11} - g_1 & v_{12} - g_2 & \cdots & v_{1n} - g_n \\ v_{21} - g_1 & v_{22} - g_2 & \cdots & v_{2n} - g_n \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} - g_1 & v_{m2} - g_2 & \cdots & v_{mn} - g_n \end{bmatrix} = \begin{bmatrix} q_{11} & q_{12} & \cdots & q_{1n} \\ q_{21} & q_{22} & \cdots & q_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ q_{m1} & q_{m2} & \cdots & q_{mn} \end{bmatrix} \quad (2.19)$$

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

The alternative A_i can belong to the border approximate area (G), the upper approximate area (G^+)or the lower approximate area (G^-) or $A_i \in \{G \vee G^+ \vee G^-\}$. The upper approximate area (G^+) represents the area where the alternative(A^+) can be found, while the lower approximate area (G^-) represents the area where the anti-ideal alternative (A^-) can be found (Figure 9).

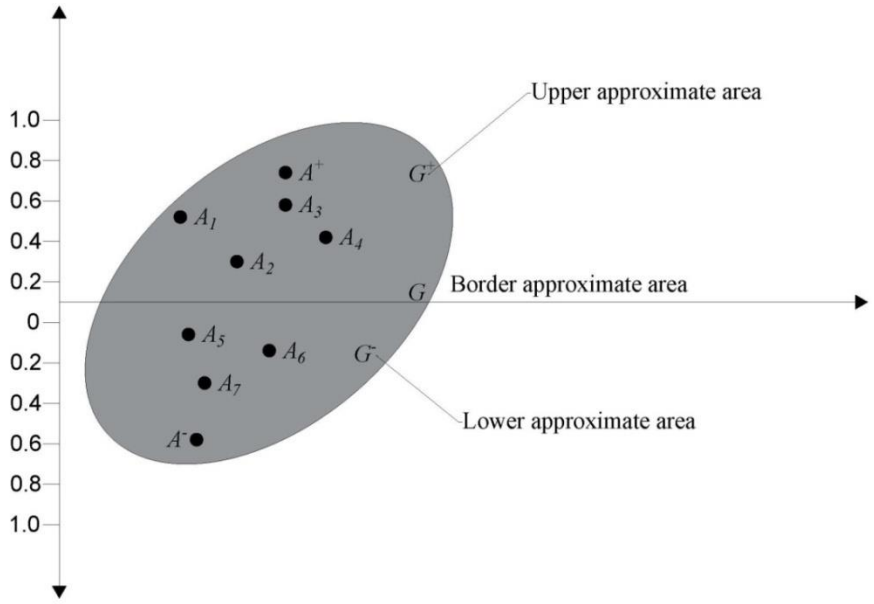

Figure 8 – Representation of the upper(G^+), lower (G^-) and border (G)approximate areas
Рис. 8 – Изображение верхней (G^+), нижней (G^-) и граничных (G) аппроксимативных областей
Слика 8 – Приказ горње (G^+), доње (G^-) и гранične (G) апроксимативне области

Belonging of the alternative A_i to the approximate area (G, G^+, orG^-) is determined by expression (2.20).

$$A \in \begin{cases} G^+ if q > g_i \\ G if q_{ij} = g_i \\ G^- if q_{ij} < g_i \end{cases} \quad (2.20)$$

In order to select the alternative A_i as the best one from the congregation, it is required that this alternative, per most criteria, belongs to the upper approximate area(G^+). If, for example, the alternative A_i per 5 criteria (from the total of 6 criteria) belongs to the upper approximate area, while by one criterion it belongs to the lower approximate area (G^-), it means that this alternative is close or equal to the anti-ideal alternative per 5 criteria. If the values $q_{ij} > 0$ or$q_{ij} \in G^+$, then the alternative A_i is

close or equal to the ideal alternative. The value $q_{ij} < 0$ or $q_{ij} \in G^{-}$ points out that the alternative A_i is close or equal to the anti-ideal alternative.

Step 6 Ranking of alternatives. Calculation of the criteria function values per alternatives (2.21) is obtained as the sum of the alternatives distances from the border approximate areas(q_i). By summing the matrix Q by rows, the final criteria function of the alternatives values is obtained:

$$S_i = \sum_{j=1}^{n} q_{ij}, j = 1,2,\dots,n, = 1,2,\dots,m \quad (2.21)$$

where n represents the total number of criteria and m represents the number of alternatives.

Best alternative selection for ATGM procurement by the application of the TOPSIS method

In the chapter entitled "ATGM development history and basic characteristics" we have explained the basic ATGM characteristics. These characteristics are always listed in weapon systems manuals because of their tactical significance. That is why these characteristics will be used as the selection criteria.

To repeat, these criteria are as follows:

- K1: Engagement range in meters,
- K2: Hit probability (0-1),
- K3: Weight in kilograms,
- K4: Price in USD,
- K5: Training simplicity,
- K6: Reliability,
- K7: Jamming resistance, and
- K8: Missile velocity,

Under the assumption that we are selecting one ATGM from the proposed four ATGMs of different manufactures, represented as A1, A2, A3 and A4, the decision matrix for a ATGM selection is presented in Table 1.

The characteristics are similar to the characteristics of real weapon systems already in use.

Table 1 – Base decision matrix
Таблица 1 – Базовая матрица решений
Табела 1 – Почетна матрица одлучивања

	K1	K2	K3	K4	K5	K6	K7	K8
A1	3000	0.35	28	1000	Low	Middle	Very High	115
A2	8000	0.95	30	5000	Very High	Very High	Very High	300
A3	2500	0.88	22	3000	High	Middle	High	186
A4	3500	0.89	25	4500	High	Middle	High	200
CRITERIA	max	max	min	min	max	max	max	max

In the given table, we can notice that, for the criteria K1, K2, K5, K6, K7 and K8, the most desirable values are the highest ones (max), while for the criteria K3 and K4 (weight and price, respectively), the most desirable are the lowest values (min).

Consider that the criteria K5, K6 and K7 are represented by quality grades; quantification by quality grades will be performed by the application of the scale presented in Table 2.

Table 2 – Quality criteria K5, K6 and K7 quantification scale
Таблица 2 – Шкала качественных и количественных критериев K5, K6 и K7
Табела 2 – Скала за квантификацију квалитативних критеријума K5, K6 и K7

Estimation	Very High	High	Middle	Low	Very low
Grade	9	7	5	3	1

By the application of the quantitative values from Table 2, the quantified matrix is presented.

Table 3 – Quantified decision matrix
Таблица 3 – Матрица количественных решений
Табела 3 – Квантификована матрица одлучивања

	K1	K2	K3	K4	K5	K6	K7	K8
A1	3000	0.35	28	1.0	3	5	9	115
A2	8000	0.95	30	5.0	9	9	9	300
A3	2500	0.88	22	3.0	7	5	7	186

	K1	K2	K3	K4	K5	K6	K7	K8
A4	3500	0.89	25	4.5	7	5	7	200
$\sqrt{\sum_{i=1}^{4} r_{ij}^2}$	9565.56	1.61	52.85	7.43	13.71	12.49	16.12	421.69

Applying the expression $x_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^2}}$, we will normalize the elements of the base decision and we will obtain the matrix presented in Table 4.

Table 4 – Normalized decision matrix
Таблица 4 – Нормализованная матрица решений
Табела 4 – Нормализована матрица одлучивања

	K1	K2	K3	K4	K5	K6	K7	K8
A1	0.314	0.217	0.470	0.865	0.219	0.400	0.558	0.273
A2	0.836	0.590	0.432	0.327	0.656	0.721	0.558	0.711
A3	0.261	0.547	0.584	0.596	0.511	0.400	0.434	0.441
A4	0.366	0.553	0.527	0.395	0.511	0.400	0.434	0.474

In order to obtain the aggravated normalized value matrix, it is necessary to multiply the values form Table 4 with the weight coefficients.

Let us assume that, in our example, an authority expert team, formed to procure ATGMs for the Armed Forces of one particular state, has reached the decision that some criteria have advantage over the others. In such a case, we can rank the before mentioned criteria as follows:

I. Hit probability,
II. Engagement range in meters,
III. Weight,
IV. Price,
V. Reliability,
VI. Training simplicity,
VII. Missile velocity, and
VIII. Jamming resistance.

Based on this requirement, we can assign numerical values, in the range from the minimum value of 0.062 for the criteria with the least importance to the value of 0.246 for the criteria with the highest

importance. Two criteria – hit probability and engagement range - have the highest values because of their tactical significance.

Engagement range in meters	w1	0.242
Hit probability	w2	0.246
Price	w3	0.116
Weight	w4	0.119
Missile velocity	w5	0.063
Jamming resistance	w6	0.062
Training simplicity	w7	0.072
Reliability	w8	0.080

By the application of the expression$v_{ij} = x_{ij} \cdot w_j \ ; \ j = 1,2 \ldots, m$ the aggravated normalized matrix is obtained and presented in Table 5.

Table 5 – Aggravated normalized matrix
Таблица 5 – Усложненная нормализованная матрица
Табела 5 – Отежана нормализована матрица

	K1	K2	K3	K4	K5	K6	K7	K8
A1	0.0759	0.0535	0.0545	0.1030	0.0138	0.0248	0.040	0.022
A2	0.2024	0.1452	0.0502	0.0390	0.0414	0.0447	0.040	0.057
A3	0.0632	0.1345	0.0677	0.0710	0.0322	0.0248	0.031	0.035
A4	0.0885	0.1360	0.0611	0.0470	0.0322	0.0248	0.031	0.038

Step 3 Determining the ideal solutions. The ideal solution A^* and the negative ideal solution A^- are determined by applying the expressions:

$$A^* = \{(\max v_{ij} \,|j \in G), (\min v_g \,|j \in G'), i = 1, \ldots, n\} = \{v_1^*, v_2^*, \ldots, v_m^*\})$$

$$A'' = \{(\min v_{ij} \,|j \in G), (\max v_g \,|j \in G'), i = 1, \ldots, n\} = \{v_1^-, v_2^-, \ldots, v_m^-\}$$

Since the ideal alternatives are those with the highest v_{ij} related to the criteria which are maximized and with the lowest v_{ij} related to the criteria which are maximized, based on Table 5, we will obtain
the ideal solution:

$$(A^*) \rightarrow A^* = \{0.2024, 0.1452, 0.0502, 0.0390, 0.0414, 0.0447, 0.0402, 0.0569\}$$

and the negative ideal solution:

$$(A^-) \rightarrow A^- = \{0.0632, 0.0535, 0.0677, 0.1030, 0.0138, 0.0248, 0.0313, 0.0218\}$$

Step 4 Determining the distances of the alternatives from the ideal solutions. By the application of the expressions:

$$S_i^* = \sum_{j=1}^{m} \left(v_{ij} - v_j^*\right)^2, i = 1, \dots, n$$

$$S_i^- = \sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2, i = 1, \dots, n$$

Euclid alternative distances from the ideal solution (S_i^*) and the negative ideal solution(S_i^-) are obtained and presented in Table 6.

Table 6 – Euclid alternative distances
Таблица 6 – Альтернативные расстояния Евклида
Табела 6 – Еуклидска растојања алтернатива

Alternatives	S_i^*	S_i^-
A1	0.1758	0.0203
A2	0.0000	0.1861
A3	0.1478	0.0900
A4	0.1189	0.1060

During the calculation of the values (S_i^*) and (S_i^-) , the elements of the normalized matrix are examined (Table 5), the ideal solutions A^* and A^- are obtained in the previous step.

Step 5 Determining the relative distance of the alternatives to the ideal solution. By the application of the expression: $Q_i^* = \frac{S_i^-}{S_i^* - S_i^-}$, $i = 1, \dots, n$ relative distance is determined for each solution, Table 7.

Table 7 – Relative proximity of the alternatives (Q_i^*)

Таблица 7 – Относительная близость альтернатив (Q_i)*
Табела 7 – Релативна близина алтернатива (Q_i^*)

Alternatives	Q_i^*	RANK
A1	0.1036	4
A2	1.0000	1
A3	0.3786	3
A4	0.4712	2

Step 6 Alternative ranking. As it has already been mentioned, the alternatives are ranked by declining valuesQ_i^*. The best alternative is the alternative which has the highest value Q_i^*, i.e. in our example the alternative $A2$. The alternative rank is presented in Table 7, i.e. $A2 \rightarrow A4 \rightarrow A3 \rightarrow A1$.

Best alternative selection for ATGM procurement by the application of the MABAC method

The procurement of an ATGM will be examined, i.e. the selection of the best alternative, using the MABAC method of the multiple-criteria decision making process.

Step 1 Base decision matrix forming(X). As in the previous example, we will examine four ATGMs. In Table 8, the characteristics of four ATMGs are presented. Table 8 also gives the base decision matrix.

Table 8 – Base decision matrix
Таблица 8 – Базовая матрица решений
Табела 8 – Почетна матрица одлучивања

Alternatives	Criteria							
	C1 (max)	*C2* (max)	*C3* (min)	*C4* (min)	*C5* (max)	*C6* (max)	*C7* (max)	*C8* (max)
A1	3000	0.350	28	1000	B	M	VG	115
A2	8000	0.950	30	5000	VG	VG	VG	300
A3	2500	0.880	22	3000	D	M	M	186
A4	3500	0.890	25	4500	D	M	M	200
w1	0.242	0.246	0.116	0.119	0.063	0.062	0.072	0.080

For evaluating the alternatives according to the C5, C6 and C7 criteria, the Likert scale (Table 9) will be applied.

Table 9 – Likert scale for evaluating alternatives
Таблица 9 – Шкала Лайкерта для оценки альтернатив
Табела 9 – Ликертова скала за евалуацију алтернатива

Nº	Linguistic designation	Numerical value
	Very Good (VG)	5
	Good (G)	4
	Middle (M)	3
	Bad (B)	2
	Very Bad (VB)	1

By the application of the Likert scale, the base decision matrix with numerical values is obtained.

Table 10 – Base decision matrix with numerical values
Таблица 10 – Базовая матрица решений
Табела 10 – Почетна матрица одлучивања

Alternatives	Criteria							
	C1 (max)	*C2* (max)	*C3* (min)	*C4* (min)	*C5* (max)	*C6* (max)	*C7* (max)	*C8* (max)
A1	3000	0.350	28	1000	2	3	5	115
A2	8000	0.950	30	5000	5	5	5	300
A3	2500	0.880	22	3000	4	3	4	186
A4	3500	0.890	25	4500	4	3	4	200
w1	0.242	0.246	0.116	0.119	0.063	0.062	0.072	0.080

Step 2 Base matrix elements normalization(X). After forming the base decision matrix(X), Table 10, the normalization of the base matrix elements is facilitated.

In our example, the "benefit" type criteria (highest values desired) are *C1, C2, C5,C6, C7* and *C8;* therefore, for calculating the normalized matrix *N* elements, the following expression will be applied:

$$t_g = \frac{x_g - x_i^-}{x_i^+ - x_i^+}$$

For the "cost" type criteria (lowest criteria values desired), which in our example are C3 and C4, the following expression is applied for calculation:

$$t_g = \frac{x_{ij} - x_i^+}{x_i^- - x_i^+}$$

By the application of the previously given expressions, the normalized matrix N is obtained and presented in Table 11.

Table 11 – Normalized matrix N
Таблица 11 – Нормализованная матрица N
Табела 11 – Нормализована матрица N

Alterna-tives	Criteria							
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*
A1	0.091	0.000	0.250	1.000	0.000	0.000	1.000	0.000
A2	1.000	1.000	0.000	0.000	1.000	1.000	1.000	1.000
A3	0.000	0.883	1.000	0.500	0.667	0.000	0.000	0.384
A4	0.182	0.900	0.625	0.125	0.667	0.000	0.000	0.459
w1	0.242	0.246	0.116	0.119	0.063	0.062	0.072	0.080

3 The calculation of the aggravated matrix V (Table 12) elements is performed by multiplying the weight coefficients, presented in the last row of the table. The weight coefficients are identical to those in the decision-making process when the TOPSIS method is used. Therefore, by the application of the expression

$$v_g = w_i \cdot t_g + w_i \ ,$$

the elements of the aggravated matrix V are obtained and presented in Table 12.

Table 12 – Aggravated normalized matrix V
Таблица 12 – Усложненная нормализованная матрица V
Табела 12 – Отежана нормализована матрица V

Alternatives	Criteria							
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*
A1	0.264	0.246	0.145	0.238	0.063	0.062	0.144	0.080
A2	0.484	0.492	0.116	0.119	0.126	0.124	0.144	0.160
A3	0.242	0.463	0.232	0.179	0.105	0.062	0.072	0.111
A4	0.286	0.467	0.189	0.134	0.105	0.062	0.072	0.117

Step 4 Determination of the border approximate areas values(G). By the application of geometric averaging for the values of the alternatives, with the expression

$$g = \left(\prod_{j=1}^{m} V_g \right)^{1/m}$$

the border approximate areas matrix $(G)$is obtained, Table 13.

Table 13 – Border Approximate Areas (BAA) matrix
Таблица 13 – Матрица граничных аппроксимативных областей (ГАО)
Табела 13 – Матрица граничних апроксимативних области (ГАО)

BAA	Criteria							
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*
g_i	0.3067	0.4024	0.1647	0.1613	0.0967	0.0737	0.1018	0.1134

Step 5 Calculation of the distance of alternatives (matrix elements) from the border approximate area(Q). The distance od the alternatives from the BAA (Table 14) is determined by the expression:

$$Q = V - G = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} - [g_1 \quad g_2 \quad \cdots \quad g_n]$$

as a reminder of the aggravated matrix (V) elements, and the values from the border approximate area matrix(G). By the application of the expression:

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

q elements are obtained, in the matrix (G)showing the distance of the alternatives from the border approximate area.

Table 14 – Matrix of the distances of alternatives from the BAA (Q)
Таблица 14 – Матрица расстояния альтернатив от ГАО (Q)
Табела 14 – Матрица удаљености алтернатива од ГАО (Q)

Alternatives	Criteria							
	C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*
A1	-0.0427	-0.1564	-0.0197	0.0767	-0.0337	-0.0117	0.0422	-0.0334
A2	0.1773	0.0896	-0.0487	-0.0423	0.0293	0.0503	0.0422	0.0466
A3	-0.0647	0.0609	0.0673	0.0172	0.0083	-0.0117	-0.0298	-0.0027
A4	-0.0207	0.0650	0.0238	-0.0274	0.0083	-0.0117	-0.0298	0.0033

Step 6 Alternative ranking. The criteria function values by alternatives are obtained by summing the elements from the matrix Q by rows, by the application of the expression:

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

The values of the criteria functions and the final rank of the alternatives are presented in Table 15.

Table 15 – Alternative ranking by the MABAC method
Таблица 15 – Альтернативное ранжирование по методу MABAC
Табела 15 – Ранг алтернатива по методи MABAC

Alternatives	Q	RANK
A1	-0.1787	**4**
A2	0.3443	**1**
A3	0.0448	**2**
A4	0.0108	**3**

Based on the obtained results, we can conclude that the alternative $A2$ is first ranked, i.e. the alternatives are ranked as follows: $A2 \rightarrow A3 \rightarrow A4 \rightarrow A1$.

Conclusion

By analyzing the data presented in Table 7(relative alternative proximity(Q_i^*) by the application of the TOPSIS method) and the data presented in Table 15 (alternative ranking by the application of the MABAC method), we can observe that the alternative A2 has the highest value and the alternative A1 has the lowest value. The alternatives A3 and A4 have relatively close values. Based on the stated, we can conclude that both methods of multi-criteria decision making are pointing that the best alternative, therefore a decision for the best ATGM weapon system, is presented in the alternative A2. Both methods show that the selection of the alternative A1 would be a wrong decision for procurement. In the applied methods, the alternatives ranking of A3 and A4 are different, so a decision maker can optionally decide (for example to lower the expenses) to select the alternative A3.

The characteristics of the alternative A2 are similar to the characteristics of the 9M133M Kornet-M ATGM, which represents one of the best, battle proven, weapon systems in world. We can conclude that the mathematical models of multi-criteria decision methods – which in our example unequivocally point to the alternative A2 - present an extremely helpful tool for decision makers.

The novelty of the method described in this paper is in the fact that a specific scientific method can be used for weapon system procurement for armed forces, therefore for gaining advancement in operational capabilities of armed forces.

The intention of the authors is to implement this method in future studies especially in the area of military decision making. The focus will be on counter insurgency operations with adversary personified in multiple militant groups. In this scenario, friendly forces will be equipped with most advanced weapon systems such as armed unmanned air vehicles (drones and loitering munitions) and unmanned ground vehicles.

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МНОГОКРИТЕРИАЛЬНАЯ МОДЕЛЬ ОПТИМИЗАЦИИ ЗАКУПОК ПРОТИВОТАНКОВЫХ КОМПЛЕКСОВ

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РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА:
27.47.19 Исследование операций,
28.00.00 КИБЕРНЕТИКА:
28.17.31 Моделирование процессов управления,
78.00.00 ВОЕННОЕ ДЕЛО:
78.25.00 Вооружение и военная техника

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Противотанковые управляемые ракеты (ПТУР) представляют собой один из самых эффективных комплексов вооружения для противодействия бронетанковым и механизированным войскам. Вооружение данным видом техники

является преимущественным для вооруженных сил любой страны. Соответствующая оценка и выбор эффективных комплексов ПТУР – важнейший фактор, влияющий на оперативные возможности вооруженных сил. Цель данной статьи заключается в представлении многокритериальных методов, являющимися полезным инструментом для решения проблемы оптимизации закупок ПТУР вооруженными силами.

Методы: Ответственным лицам, принимающим решения по закупкам ПТУР предлагается внедрение многокритериальных методов TOPSIS (Technique for Order Preference by Similarity to Ideal Solution − Метод для выбора порядка предпочтения по сходству с идеальным решением) и MABAC (Мультиатрибутивная мдоель сравнения граничных аппроксимативных областей). В данной статье представлены возможные решения по четырем моделям ПТУР. Описанные ПТУР представлены как варианты A1, A2, A3 и A4.

Результаты: На основании методов, описанных в данной статье, можно сделать вывод, что самым благоприятным является вариант A2, а соответственно и лучшим решением при выборе ответствтвенными лицами, принимающими решения касательно закупок данной модели ПТУР.

Выводы: Приходим к выводу, что математические модели многокритериальных методов принятия решений, представленные в данной статье, недвусмысленно указывают на альтернативу с лучшими характеристиками и представляют собой выигрышный и чрезвычайно удобный инструмент для ответственных лиц, принимающих решения.

Ключевые слова: TOPSIS, MABAC, закупка систем вооружения, многокритериальное принятие решений.

ИЗБОР ПРОТИВОКЛОПНИХ ВОЂЕНИХ РАКЕТА МОДЕЛОМ ВИШЕКРИТЕРИЈУМСКОГ ОДЛУЧИВАЊА

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ОБЛАСТ: математика, логистика
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод: Противоклопне вођене ракете (ПОВР) представљају једно од најефикаснијих оруђа у супротстављању оклопним и

механизованим јединицама. Опремање овим оруђима представља императив оружаних снага било које државе. Адекватна евалуација и избор ефикасних ПОВР представља важан фактор који утиче на оперативне способности оружаних снага. Циљ овог рада јесте да прикаже да методе вишекритеријумског одлучивања представљају користан алат за решавање проблема оптималне набавке ПОВР за оружане снаге.

Методе: Имплементација TOPSIS (Technique for Order Preference by Similarity to Ideal Solution – техника за одабир наруџбине по сличности са идеалним решењем) и MABAC (Multi Attributive Border Approximation Area Comparison – вишеатрибутивно упоређивање граничних апроксимативних области) метода биће предложене за доносиоце одлука за решавање проблема набавке ПОВР. У раду су предложене четири врсте ПОВР као могућа решења. Наведене ПОВР приказане су као алтернативе A1, A2, A3 и A4.

Резултати: Имплементација метода довела је до закључка да алтернатива A2 има највишу вредност и да представља најбољи избор који доносиоци одлука могу донети за избор ове врсте ПОВР.

Закључак: Математички модели вишекритеријумског одлучивања, примењени у овом раду, недвосмислено указују на алтернативу са најбољим карактеристикама, па представљају захвалан и изузетно користан алат за доносиоце одлука.

Кључне речи: TOPSIS, MABAC, набака оружаних система, вишекритеријумско одлучивање.

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MULTICRITERIA APPROACH TO THE SELECTION OF THE TRAINING MODEL OF DANGEROUS GOODS TRANSPORT ADVISORS IN THE MINISTRY OF DEFENSE AND THE SERBIAN ARMY

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Abstract:

Introduction/purpose: Progress of science and development of new technologies brings increased everyday use of goods with potential human safety and health hazards. The aim of this paper was to select a model for training individuals who are to perform the function of dangerous goods transport advisors in the Ministry of Defense (MD) and the Serbian Armed Forces (SAF).

Methods: The problem was solved through the use of the AHP (Analytic Hierarchy Process) with ten subject-matter experts involved, who all contributed - within their individual competency level, with different individual weight of knowledge - to the final decision.

Results: The stability of the final decision was confirmed with a dynamic sensitivity analysis through the use of Expert Choice 2000 software.

Connclusion: The results of the conducted research favored the model by which the training should be conducted relying on one's own resources.

Key words: model, training, transport safety advisor, dangerous goods.

Introduction

Industrial development contributed greatly to the development of transportation and through that to greater presence of dangerous goods in transportation activities. Every participant of the process of dangerous goods transport is exposed to the risk of possible accidents during the dangerous goods transport. Dangerous good transport accidents also present risk for individuals not directly involved in the process of goods transport, their material goods and the environment in which they live.

Dangerous goods transport in the armed forces is very pronounced given the fact that the majority of members of the armed forces are, by nature of the job, in everyday contact with some sort of dangerous goods. Precisely, this fact obliges armed forces to undertake many activities to prevent dangerous goods transport accidents.

Mode of transport and responsibilities of individuals involved in the transport of dangerous goods are prescribed through legal norms at national and international levels. Policy of dangerous goods transport in the MD and the SAF (Official Military Gazette, 8/2018) regulates transport of dangerous goods within the MD and the SAF, as well as by other armed forces or organisations which make use of the transportation infrastructure of the Republic of Serbia (RS), in accordance with a separate agreement. First and foremost, the mentioned policy is in accordance with the national Law of dangerous goods transport (Official Gazette of the RS, 95/2018) as well as with international agreements that regulate dangerous goods transport for different means of transportation.

For dangerous goods transport to function without problems and for it to be in accordance with regulations, a need arose for a person who has the knowledge of duties and responsibilities of all participants in the said process. That person is a Dangerous goods transport advisor.

Dangerous goods transport advisors are professionals in charge of full compliance with regulations during dangerous goods transportation activities performed by an organisation. This function can be executed only by individuals who attended prescribed training and are in possession of adequate certificates for the said function.

According to the European Regulations concerning the international transport of dangerous goods by road ADR, a Dangerous goods transport advisor must be appointed within all organisations who participate in the process of dangerous goods transport or who are involved in other activities related to dangerous goods transport (packaging, filling, loading or unloading). For the mentioned positions, many individuals permanently hired by the organisation may be appointed, or the organisation could outsource and hire on contract when needed.

Duties of the Dangerous goods transport advisor are defined by the ADR and are related to:

– monitoring of compliance with dangerous goods transport regulations,

– giving advice to decision makers within the organization for all activities related to dangerous goods transport, and

– creation of yearly reports about the activities and events related to dangerous goods transport.

The aim of this paper was to select a model for training individuals who are to perform functions of dangerous goods transport advisors in the MD and the SAF. The problem was solved through the use of the AHP (Analytic Hierarchy Process) with participation of multiple decision makers. The decision makers in the AHP evaluation of the said problem were members of the MD and the SAF, performing duties of organisation and conduct of dangerous goods transport.

The paper is composed of six sections, including Introduction and Conclusion. "Dangerous goods in transport", is the subject of the second section of this paper. The third section of the paper, entitled "AHP decision-making", describes the procedure for implementing the AHP at the individual and group level. The fourth section of the paper entitled "Formulation problem" describes the problem and presents the AHP hierarchy of decision-making problems. The "Results and discussion " are presented in the fifth section of the paper. The Conclusion section emphasizes the key benefits of the conducted research.

Dangerous goods transport

For a more accurate understanding of potential hazards associated with working with some substance, it is necessary to know and analyze a large number of physical and chemical properties of substances, as e.g. (Vidović et al, 2019):

– type of danger,
– physical state,
– viscosity,
– boiling point,
– melting temperatures,
– density,
– the voltage of the steam,
– flammability temperature,
– auto-ignition temperature,
– limits of explosive mixtures,
– reactivity with respect to other substances, etc.

The term a "dangerous substance" refers to a substance with its physical-chemical characteristics, which are determined on the basis of the recognized and appropriate criteria. From the standpoint of chemistry, the mentioned term "dangerous substance" is not adequate to define the notion, but it would be the term "hazardous substance" (Jovanović et al, 2010).

Using the wrong term may lead to erroneous determination of the status of dangerous substances during the transport process, which directly affects both the application of appropriate recovery procedures in case of accidents, and the application of methods that are contrary to the international rules and obligations.

"Dangerous goods" refers to the keyword when the hazardous matter-substance is contained in an appropriate packaging - container or a vehicle during the transport process. There are specific criteria for potential risks from hazardous substances which determine the transport conditions (Jovanović et al, 2010).

According to the Rulebook of the Transport of Dangerous Goods in the Ministry of Defense and the Army of Serbia (Official Gazette 8/2018) and the Law of the Transport of Dangerous Goods (Official Gazette of the Republic of Serbia, 95/2018), dangerous goods are substances and articles forbidden from transport, i.e. allowed if transport is performed under international agreements and regulations for the transport of dangerous goods by the type of traffic (ADR, RID, ADN).

There are numerous examples of unprofessional and negligent treatment during handling (manipulating) in transport of dangerous goods, which have resulted in the suffering of people, property and environmental degradation (Pamučar et al, 2019; Pamučar, 2020).

The consequences of road traffic accidents with vehicles transporting dangerous goods may also be such as to amount to a catastrophe. As e.g.:

– On 6th December 1917, in Halifax (Nova Scotia), Figure 1, there was a collision due to the accident of the French ship "Mont Blanc" and the Norwegian ship "SS imo", in the access port and channel - Halifax, at a low speed of about 2.5 km/h. The Mont Blanc ship was carrying about 3.2 million pounds of picric acid and TNT for the needs of the French army in World War I. The effect of the explosion was in fragments of the ship, a shock wave and a tsunami 18 meters high, created by the explosion. The estimated temperature of the explosion was about 5000 ° C. A pyrotrophic cloud rose to an altitude of about 3600m. The number of victims has never been precisely determined. It is believed that about 1,600 people were killed immediately, and about 400 succumbed to injuries, 9,000 were injured, 1,600 homes were destroyed in a series of fires and 12,000 homes were damaged. The industrial sector of the city was completely destroyed. The Halifax disaster was the unofficial start of systematic consideration of hazardous substances (Janković, 2016).

Figure 1 – Disaster in Halifax in 1917, the explosion of the ship and the consequences (Janković, 2016)
Рис. 1 – Взрыв в Галифаксе в 1917 году, кораблекрушение вследствие взрыва и его последствия (Janković, 2016)
Слика 1 – Катастрофа у Халифаксу 1917. године, последице експлозије брода (Janković, 2016)

– In 1978, in Los Alfaques (Spain), a fuel tank was overloaded. Due to high heat and pressure, the tank exploded and the fuel caught fire, killing 216 people (Figure 2).

Figure 2 – Consequences of an accident on the way to Los Alfaques in 1978.
Рис. 2 – Последствия ДТП в Лос-Альфакесе в 1978 году.
Слика 2 – Последице акцидента на путу у Лос Алфакуесу 1978. године

– On 12th July 2012, in Okobie town in Nigeria, there was an explosion of a road tanker for gas transport (Figure 3). One hundred and twenty one people were killed in the accident and 75 were injured.

Figure 3 – Consequences of the accident in Okobie–Nigeria, 12th July 2012. (Janković, 2016)
Рис. 3 – Последствия аварии в Окобие, Нигерия, 12 июля 2012 г. (Janković, 2016)
Слика 3 – Последице акцидента у Окобие – Нигерија, 12. јул 2012. године (Janković, 2016)

– In 1986, in Šabac, Serbia, a railroad tank carrying ammonia (NH3) hit an overpass from below. The valves got loose and the gas began to leak. Favorable wind and the timely intervention of specially trained workers prevented a more serious catastrophe.

To avoid this and similar situations and reduce risks to a minimum, it is necessary that all personnel who come into contact with dangerous goods, or all people involved, comply with regulations and guidelines that define the handling of dangerous goods, as well as be properly trained and prepared for their work.

On the basis of these problems, experts of the United Nations gave basic recommendations and guidelines for international agreements, i.e. procedures related to Conventions about different methods of transport of dangerous goods (Vidović et al, 2019; Jovanović et al, 2010; Janković, 2016; Jovanović, 2004; Petrović, 2004), Figure 4:

– European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR),

– Regulations concerning the International Carriage of Dangerous Goods by Rail (RID),

– International Civil Aviation Organization – Tehnical Instructions for the Safe Transport of Dangerous Goods by Air (ICAO–TI),

– International Air Transport Association – Dangerous Goods Regulations (IATA–DGR),

– International Maritime Dangerous Goods–Code (IMDG–CODE),

and

– European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN).

Figure 4 – International agreements on transport of dangerous goods
Рис. 4 – Международные соглашения по перевозке опасных грузов
Слика 4 – Међународни споразуми о транспорту опасне робе

AHP decision making

The analytical hierarchical process (Saaty, 1980) is one of the most exploited methods for decision making when multiple criteria are considered. (Escobar, 2004; Vaidya & Kumar, 2006; Altuzarra et al, 2007; Ho, 2008; Arnette et al, 2010; Subramanian & Ramanathan, 2012; Bernasconi et al, 2014; Žižović & Pamučar, 2019; Biswas et al, 2019; Stanković et al, 2019; Durmić et al, 2020; Janković & Popović, 2019)

The method is “analytical” and “hierarchical” because decision making participants disassemble the root problem of decision making (the aim) to several decision-making elements and create hierarchical relations between them. The obtained hierarchy has a multilevel composition. At the top of the hierarchy is the aim, followed by the criteria at the next level and the alternatives at the bottom. This type of hierarchy

presents the base problem of AHP decision making, but also reflects problems present in other hierarchy types, such as three-level hierarchy when a sub-criteria level is found between the criteria and the level of alternatives. Likewise, hierarchies with only two levels pose the same problems when only the aim and the alternative layers are found.

In order to determine relations between the AHP hierarchy elements, one has to compare groups of elements (couples) against the elements on the higher level of hierarchy. The comparison is done through rating and the use of the Saaty rating scale, as shown in Table 1.

Table 1 – Saaty rating scale
Таблица 1 – Оценочная шкала Саати
Табела 1 – Скала оцена Saaty

Meaning	Rating $\left(a_{ij}\right)$
The absolute dominance of the element i over element j	9
Very strong element dominance i over element j	7
Strong element dominance i over element j	5
Poor element dominance i over element j	3
The same importance of element i and element j	1
Poor element dominance j over element i	1/3
Strong element dominance j over element i	1/5
Very strong element dominance j over element i	1/7
Absolute dominance of the element j over element i	1/9
(Intermediates)	(2,4,6,8)

Besides the Saaty rating scale, many other scales could be used, e.g. the Lootsma scale (Lootsma, 1988; Lootsma, 1990; Lootsma et al, 1990; Muravev & Mijic, 2020; Ma et al, 2011). The Saaty rating scale is most common and its linear part is composed of whole number values (1 to 9), while the non linear part is composed of appropriate reciprocal values (1/1-9).

When a participant in the AHP, on a specific hierarchy level, rates semantically n elements of that level against the elements of the higher level using the scale in Table 1, its semantic rates from the left column are shown in equivalent number values from the right column and are entered in the square matrix A. The matrix is positive and reciprocal (symetrical in relation to the main diagonal), which means that the elements in the upper matrix triangle are reciprocal to the elements of the

lower matrix triangle, while the elements on the main diagonal are equal to 1 ($a_{ij} = 1/a_{ji}$, for each i and j; $a_{ii} = 1$ for each i), Matrix 1.

$$A = \begin{bmatrix} a_{11} & a_{12} & ... & a_{1n} \\ a_{21} & a_{22} & ... & a_{2n} \\ ... & ... & ... & ... \\ a_{n1} & a_{n2} & ... & a_{nn} \end{bmatrix} \quad (1)$$

If the standard Saaty scale is used, then each of a_{ij} can have one of 17 values from the discrete interval $[1/9, 9]$. When filling in the matrix A, the transit rule should be followed $a_{ij} = a_{ik} * a_{kj}$ for every $i, j, k = 1,...,n$. Determining the weights of the compared elements based on the numerical values from the matrix is called prioritization. Prioritization is the process of determining the priority vector $w = (w_1,...,w_n)^T$ from the matrix A, where every $w_i \succ 0$ implicates $\sum_{i=1}^{n} w_i = 1$. There are multiple prioritisation methods, but the most used ones are the Additive normalisation method, the Eigenvector method, and the Logarithmic least squares method. (Blagojević, 2015; Blagojević et al, 2020).

Because of its simplicity and frequency of use, the additive normalization method was used in this paper (additive normalization method – AN). In order to determine the vector of priorities w, it is sufficient to divide each element from a given column of the matrix A by the sum of the elements of that column (normalization), then to compile the elements in each type, and finally to divide each resulting sum by the rank of the matrix n. This procedure is described by relations 2 and 3:

$$a_{ij}' = \sum_{i=1}^{n} a_{ij}, ij = 1,2,...,n \quad (2)$$

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}'}{n}, i = 1,2,...,n \quad (3)$$

Based on the evaluation, the chosen method of prioritization determines the local weights of the decision elements, and the synthesis, i.e. the additive synthesis, ultimately determines the weights of the alternatives at the lowest level relative to the element at the highest level (goal), which determines ending individual decision making by the AHP. The additive synthesis is given by relation 4:

$$u_i = \sum_j w_j d_{ij} \quad (4)$$

– u_i – the final (global) priority of the alternative i,

– w_j – weight of the alternative j,

– d_{ij} – the local weight of the alternative i relative to the criterion j.

In addition to the prioritization methods, one of the important features of the AHP is that it checks the consistency of decision maker evaluations at all levels of the hierarchy. For consistency checking (Saaty, 1977), the consistency ratio (CR) is suggested. It is used in AN prioritization methods. Calculating the consistency ratio includes two steps. The first step, the consistency index (CI) is calculated using relation 5:

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (5)$$

– n – rank of the matrix,

– λ_{max} – the maximum eigenvalue of the comparison matrix.

The second step, the consistency ratio (CR) is calculated as the ratio of the consistency index (CI) and the random index (RI), relation 6:

$$CR = \frac{CI}{RI} \quad (6)$$

The random index is in direct relation to the rank of the matrix (RI), Table 2.

Table 2 – Random index values
Таблица 2 – Значения случайного индекса
Табела 2 – Вредности случајног индекса

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

When the obtained CR is ≤ 0.10, it is considered that the participant of the AHP performed the analysis and evaluation in a consistent manner. (Jandrić & Srđević, 2000; Kazimieras Zavadskas et al, 2020). In cases when CR is > 0.10, the participant of the AHP should repeat the process and modify its evaluation process.

It is becoming a common practice in the creation of scientific papers where decision-making processes based on the opinions of single individuals are considered non-objective. That is why nowadays group decision making is more and more applied, i.e. decision making is based on opinions and suggestions of multiple participants in the process.

In the AHP, for the synthesis of separate decisions into a final, or group decision, multiple methods exist. Two most common methods for final decision making are (Ramanathan & Ganesh, 1994; Forman & Peniwati, 1998):

– Aggregation of Individual Priorities – AIP and
– Aggregation of Individual Judgments – AIJ.

To integrate individual decisions into group decisions, this paper uses the AIP method. Aggregation was perfomed using the *Weight Arithmetic Mean Method–WAMM.* The alternative A_i and its weight value $w_i^{(k)}$ (priority) for the k-th decision maker are given. If all the members of the group (g) are assigned appropriate weight values α_k, the weight arithmetic mean is:

$$w_i^{(g)} = \sum_{k=1}^{m} w_i^{(k)} \alpha_k \tag{7}$$

– $w_i^{(g)}$ – final (composite) priority of the alternative A_i,
– m – number of decision makers (group members).

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By assumption, the individual weights of the group members α_k are previously additively normalized $\sum_{k=1}^{m}\alpha_k = 1$. A final additive normalization of the priorities of all alternatives is needed.

The sensitivity analysis of the final decision is a very important characteristic of the AHP. It is conducted to determine if the changes of the entry parameters influence the score list of alternatives in the final decision. Multiple software solutions exist for the sensitivity analysis and Expert Choice is one of the most used ones.

If the changes of the entry parameters for 5 % in all combinations do not cause changes in the score list of alternatives, the final AHP decision is considered stable (Hot, 2014).

Problem formulation

The training of Dangerous goods transport advisors for the MD and the SAF is held in certified civilian institutions. Such a training model presents problems that affect functioning of transportation units within the MD and the SAF, among which the most important ones are:

- Mutual dependency between the training plan terms and the capability of civilian training institutions,
- Weak teritorial availabilty of civilian institutions for dangerous goods transport advisor training outside regional hubs,
- Training costs, and
- Personal costs for trainees.

That said, in order to analyse the existing approach to training Dangerous goods transport advisors within the MD and the SAF, a group of experts in the field of dangerous goods transport, made of ten transportation officers from the MD and the SAF, was surveyed.

The first part of the survey allowed the experts to give their opinions on possible training models for Dangerous goods transport advisors of the MD and the SAF. The second part of the survey guided the experts in determining the criteria based on which the training model was to be selected. The process used in decision making about the training model was the analytic hierarchy process (AHP).

The setup of the AHP hierarchy for deciding on the model of training candidates for the function of Dangerous goods transportation advisors is shown in Figure 5.

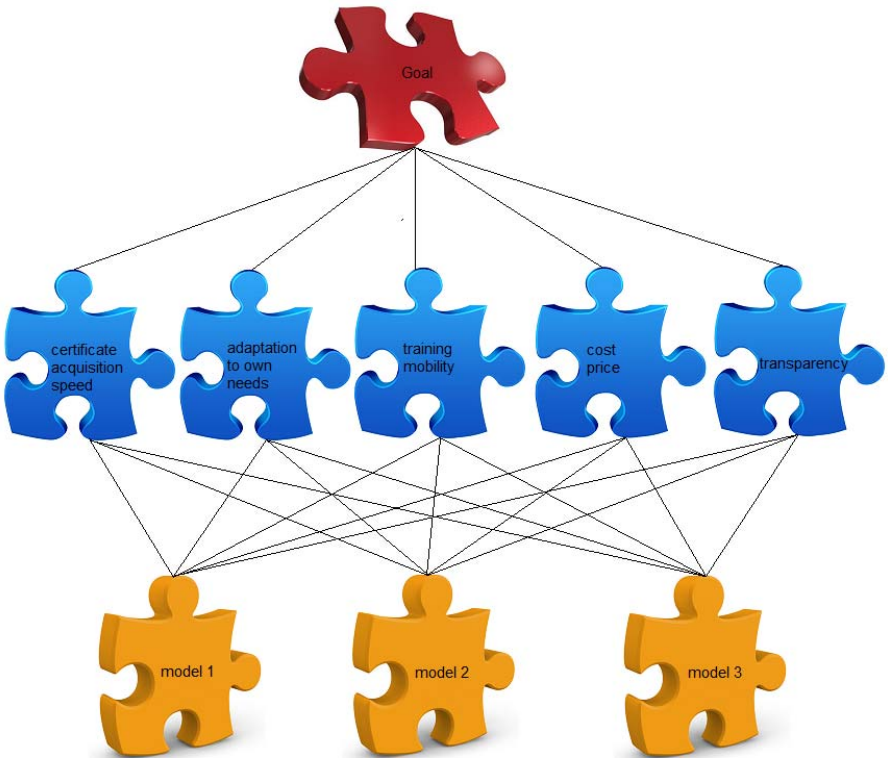


Figure 5 – Setting up the AHP hierarchy
Рис. 5 – Настройка иерархии АНР
Слика 5 – Постављање АНР хијерархије

Figure 5 shows a standard decision making problem where the aim (the training model) is at the top of the hierarchy. On the next level, there are criteria (certificate acquisition speed, adaptation to own needs, training mobility, cost price, transparency). Models which should be used in training Dangerous goods transportation advisors are represented by alternatives in the AHP hierarchy, and are located at the bottom level:

– model 1 – Model in which both training and certification would be conducted in accordance with the present practice, i.e. relying on the civilian sector,

– model 2 – Model in which training would be conducted within armed forces and certification would be conducted in the civilian sector,

– model 3 – Model in which both training and certification would be conducted within armed forces units using own resources.

Competency assessment of expert group members was conducted according to the approach which Djorovic (2003) recommends for competency assessment of transportation support experts, which accounts for three assessment aspects:

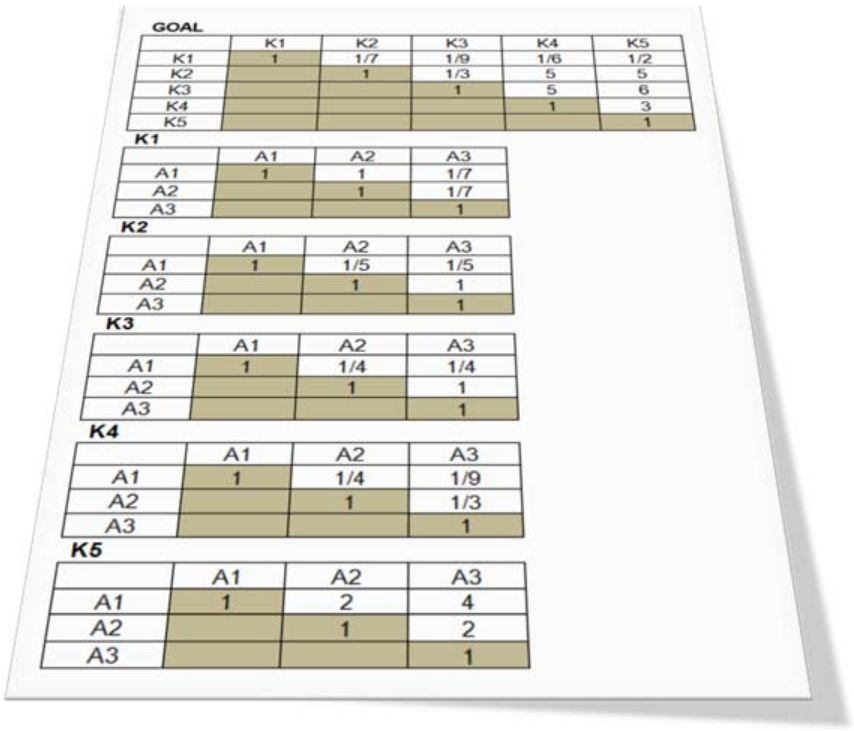
- Objective assessment,
- Assessment of the source of the argument, and
- Subjective assessment of the expert.

A dettailed overview of the above mentioned approach to the competency assessment of the experts is shown in Djorovic (2003) and Lukovac (2016). The results of the competency assessment process of the experts in this research have confirmed their competencies for research participation, see Table 3.

Table 3 – Competence assessment
Таблица 3 – Оценка компетентности
Табела 3 – Оцена компетентности

Experts	Expertise assessment
1.	0.6675
2.	0.67
3.	0.5413
4.	0.69
5.	0.4988
6.	0.525
7.	0.4763
8.	0.5063
9.	0.64
10.	0.57
Group assessment	0.57852

After being introduced with the AHP methods, subject-matter experts were given forms to evaluate the elements of the AHP hierarchy for the choice of a model for training candidates for the function of Dangerous goods transport advisors. Figure 6 shows a completed form for the AHP evaluation of one of the members of the expert group.



GOAL

	K1	K2	K3	K4	K5
K1	1	1/7	1/9	1/6	1/2
K2		1	1/3	5	5
K3			1	5	6
K4				1	3
K5					1

K1

	A1	A2	A3
A1	1	1	1/7
A2		1	1/7
A3			1

K2

	A1	A2	A3
A1	1	1/5	1/5
A2		1	1
A3			1

K3

	A1	A2	A3
A1	1	1/4	1/4
A2		1	1
A3			1

K4

	A1	A2	A3
A1	1	1/4	1/9
A2		1	1/3
A3			1

K5

	A1	A2	A3
A1	1	2	4
A2		1	2
A3			1

Figure 6 – AHP evaluation form
Рис. 6 – Форма оценки AHP
Слика 6 – Образац за AHP вредновање

Results and discussion

Processing of the gathered forms for the AHP evaluation was done by the use of Expert Choice 2000 (EC 2000) software, which yielded the results shown in Table 4.

Compiling individual expert decisions into a final decision was done through compiling individual priorities according to the relations shown in Equation 7. In final decision making, Table 5, the experts used the weighted normalised values of their evaluated competences.

Table 4 – Expert decisions
Таблица 4 – Экспертные решения
Табела 4 – Експертске одлуке

Experts	A1	A2	A3
1.	0.12	0.42	0.46
2.	0.12	0.42	0.46
3.	0.18	0.17	0.65
4.	0.52	0.35	0.13
5.	0.52	0.31	0.17
6.	0.67	0.13	0.21
7.	0.27	0.37	0.36
8.	0.18	0.17	0.65
9.	0.12	0.42	0.46
10.	0.27	0.37	0.36

Table 5 – Final decision
Таблица 5 – Окончательное решение
Табела 5 – Коначна одлука

Models	Importance	Rang
A1	0.29	3
A2	0.32	2
A3	0.39	1

Figure 7 holds the results of the final decision.

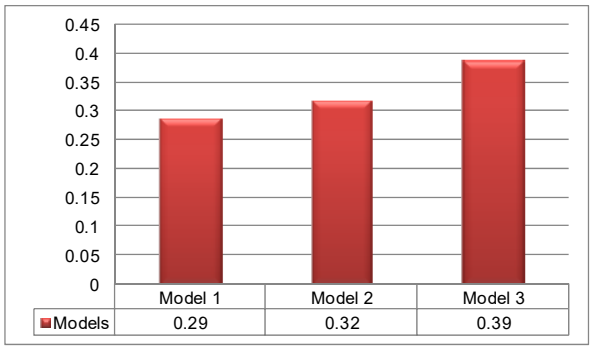


Figure 7 – Graphic representation of the final decision
Рис. 7 – Графическое изображение окончательного решения
Слика 7 – Графички приказ коначне одлуке

Figure 7 shows that the decision makers favored “model 3”. A sensitivity analysis of the final decision made by the members of the expert group was conducted with the use of EC 2000 software. Noting that the changing of the initial entry parameters by 5% did not cause the alternative range to change, the final decision made by the members of the experts group can be considered stable.

In the end, based on the conducted AHP evaluation, it can be concluded that training and certification of dangerous goods advisors in the MD and the SAF should be conducted relying on own resources.

Conclusions

Dangerous goods transport, based on the means of transport, necessitates full compliance of regulations at all levels (including organisational, national and international). Prevention of accidents which may occur during dangerous goods transport is a duty for all participants. The decision on the model of training candidates for the function of Dangerous goods transport advisors stems from multivariate analysis and participation of more experts with adequate competencies. For the purpose of this paper, the AHP was used in a group context. Managing the group decision process can be done in many different ways. One of them is favoring decisions of specific participants through the process of evaluation of participants. To make group decision more objective, individual participants of this AHP evaluation had their decisions weighted with the use of normalization of their competencies. The decision obtained after the AHP evaluation process points out that the model for training candidates for the function of Dangerous goods transport advisors and certification which should be used is the one where only the resources of the MD and the SAF were used, without external assistance.

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МНОГОКРИТЕРИАЛЬНЫЙ ПОДХОД К ВЫБОРУ МОДЕЛИ ОБУЧЕНИЯ СОВЕТНИКОВ ПО ОПАСНЫМ ГРУЗАМ В МИНИСТЕРСТВЕ ОБОРОНЫ И ВООРУЖЁННЫХ СИЛАХ РЕСПУБЛИКИ СЕРБИЯ

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РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА:
27.47.19 Исследование операций,
28.00.00 КИБЕРНЕТИКА:
28.17.31 Моделирование процессов управления,
73.00.00 ТРАНСПОРТ:
73.47.12 Организация управления и автоматизированные системы управления транспортом

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Научные достижения и развитие новых технологий способствуют повседневному потреблению нарастающего количества товаров, которые могут вызвать неблагоприятные последствия для безопасности и здоровья человека. Цель данной статьи заключается в представлении модели, в соответствии с которой должно проводиться обучение лиц, занимающих должность советника по безопасности перевозки опасных грузов в Министерстве обороны (МО) и Вооруженных силах Республики Сербия (ВСРС).

Методы: Проблема решалась с помощью AHP (Analytic Hierarchy Process), в процессе решения участвовали десять экспертов, которые в соответствии с их оцененной компетенцией внесли каждый свой индивидуальный вклад в окончательное решение задачи.

Результаты: Стабильность окончательного решения подтверждена динамическим анализом чувствительности с помощью программы Expert Choice 2000.

Lukovac, V. et al, Multicriteria approach to the selection of the training model of dangerous goods transport advisors in the Ministry of Defense and the Serbian Army, pp.828-851

Выводы: Результаты проведенного исследования свидетельствуют о преимуществах модели, согласно которой обучение должно проводиться исходя из собственных возможностей.

Ключевые слова: модель, обучение, советник по транспортной безопасности, опасные грузы.

ВИШЕКРИТЕРИЈУМСКИ ПРИСТУП ИЗБОРУ МОДЕЛА ОБУКЕ САВЕТНИКА ЗА БЕЗБЕДНОСТ ТРАНСПОРТА ОПАСНЕ РОБЕ У МИНИСТАРСТВУ ОДБРАНЕ И ВОЈСЦИ СРБИЈЕ

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ОБЛАСТ: математика, транспорт
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Напредак науке и развој нових технологија доприноси свакодневној употреби све већег броја роба које могу изазвати нежељене последице по безбедност и здравља људи. Циљ овог рада јесте избор модела по којем би требало вршити оспособљавање лица за обављање функције саветника за безбедност транспорта таквих врста роба у Министарству одбране (МО) и Војсци Србије (ВС) .

Методе: Проблем је решаван помоћу AHP (Analytic Hierarchy Process) у којем су учествовала десеторица експерата, а који су захваљујући својој компетентности допринели коначној одлуци.

Резултати: Стабилност коначне одлуке потврђена је динамичком анализом осетљивости помоћу софтвера Expert Choice 2000.

Закључак: Резултати спроведеног истраживања фаворизовали су модел по којем би обуку требало спроводити ослањајући се на сопствене капацитете.

Кључне речи: модел, обука, саветник за безбедност транспорта, опасна роба.

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TEACHING IN CONDITIONS OF DIFFICULT KNOWLEDGE TRANSFER DUE TO THE STATE OF EMERGENCY CAUSED BY THE PANDEMIC

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FIELD: Information technology
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: This paper presents the transformation of the current, classical approach to teaching. Online platforms enable students with and without disabilities to follow classes without hindrance during the lecture period. After the lecture, they are allowed to view video and presentation materials. The main advantage of this way of teaching is the possibility of attending classes from any location and from any device; it is only important to be connected to the Internet.

Methods: Full integration with the already existing Faculty Information System has been performed. The paper describes a new approach to teaching and illustrates the expected benefits of online teaching. The platforms used in this integration are Microsoft Azure, Microsoft Office 365 Admin, Microsoft Teams, Microsoft Stream and Microsoft SharePoint.

Results: The result of the test of work with students showed that by introducing a system for online teaching, we directly affect the improvement and quality of teaching.

Conclusion: Considering all the results, it can be concluded that the transition to the online way of teaching allows end listeners a comprehensive transfer of knowledge as well as re-listening to the same.

This model can be used for an unlimited number of users in all Institutions, regardless of whether the field of activity of these Institutions is of educational origin.

Key words: education, online learning, teaching analysis, Microsoft Teams, Microsoft Azure.

Introduction

Starting from March 2020, almost all spheres of business were forced to switch to the online way of doing business. The new health crisis has demanded that more and more organizations use telecommuting to preserve and respect social and spatial distance. Therefore, the conditions created by the emergence of the Covid-19 pandemic provide an opportunity for intensive research into teleworking, all for the purpose of adapting to this way of everyday work as well as maintaining the current global economy. This way of working leads to the flexibility of employees in various types of business and provides a completely new way of working for the end users of the system. Switching to this way of working has increased productivity, reduced the costs of employers as well as employee fatigue due to daily commuting (Purcarea & Purcarea, 2008). Certainly, the biggest problem in terms of this way of working is reflected in the adaptation to new technologies as well as raising awareness of the necessary computer knowledge of the end users of the system.

This paper describes all parts of the system that are analyzed for the purposes of teaching at university academic studies. Also, the implementation process as well as the student and faculty approach to the platform will be described.

Compared to classical teaching, online teaching offers many more benefits for students. Certainly, the biggest advantage of online teaching is the re-viewing of recorded materials as well as access to the platform from any location and any device that has Internet access.

Pokorni states in his work that in the middle of the nineties, a new term, modern distributed learning, was created. This type of distance learning is a system and process of connecting students with distributed educational resources. Distance education in relation to the classical way of education shows advantages such as enabling lifelong learning and professional development, participation in the highest quality and most prestigious programs, choosing one's way of learning as well as many others (Pokorni, 2009).

The paper combines a practical analysis of teams as a computer-supported collaborative learning process (CSCL) and explains what

teams can offer to teachers in higher education institutions. This paper argues that the online learning process develops shared learning as a process of peer interaction that the mentor mediates and structures. The discussion can be promoted by presenting certain concepts, problems or scenarios, and is led by efficiently directed questions, introduction and clarification of concepts and information and references to previously learned material (Bozkurt, 2019a), (Bozkurt, 2019b), (Bozkurt et al, 2019), (Bozkurt & Sharma, 2020).

Existing solutions

There are a number of software solutions for online video calls on the market. This part of the area gained its greatest popularity with the appearance of the Covid-19 global pandemic. Software platforms such as Microsoft Teams, Zoom, Google Meet, Cisco Webex and many others have shifted much of their revenue to developing additional plug-ins to upgrade their existing software solutions. In this way, each company tries to position itself as a market leader and maintain its popularity with end users.

Among the large number of platforms for online video chats, the Microsoft Teams platform stood out the most. In addition to using video calls, the platform offers the possibility of using chat messages, video recording of meetings as well as creating tests directly within the platform.

Tsai predicts that by the end of 2021, Microsoft Teams will be in use in more than 41% of companies worldwide (Tsai, 2018). The current situation is such that the Microsoft Teams platform is used daily by more than 75 million active users. Statistically, in July 2019, the Microsoft Teams platform had 62 million active users. Based on these data, we come to the conclusion that the number of users of this platform has increased rapidly with the emergence of the Covid-19 pandemic.

Microsoft Teams offers the ability to integrate with the existing Moodle solutions. This provides an opportunity for educational institutions to synchronize Moodle courses, grades and assignments. By synchronizing these two platforms, we create a whole in which all modules are located on one platform (Martin & Tapp, 2019).

Starting from the assumption that the realization of teaching depends on the educational system and the way of knowledge transfer, we come to the conclusion that the introduction of online teaching has badly affected the quality of teaching of educational institutions not accustomed to such work (Misha et al, 2020), (Fabiano & Radenović,

2020a), (Fabiano & Radenović, 2020b), (Fabiano & Radenović, 2020). Daisy and her expert team believe that the online way of transferring knowledge has caused a lot of damage to medical educational institutions in many ways. The greatest negative impact is visible in the area of practical knowledge and practical exercises. The problem that arises is that practical classes cannot be held on real examples in specialized laboratories. Another negative impact is that practical work in the real environment in the form of going to the hospital is not possible because a large number of hospitals have become Covid-19 hospitals and for that reason students do not have access to them (Henderson et al, 2020), (Juan, 2021). However, despite the challenges posed by the pandemic in providing health care, this type of virtual learning represents acceptable results of knowledge transfer. This way of knowledge transfer opens the possibility of expanding virtual teaching in all types of education around the world.

Project description

It is important to note that full integration with the already existing Faculty Information System has been performed. It would be good if after enrollment the student gets access to his Microsoft Office 365 account and with the help of the same access to the platform itself. Students have Microsoft Office 365 calendars in which the teaching dates in the current year are predefined, created by professors and assistants before the beginning of the semester. It is recommended that all students be able to follow the course optionally and that the system be fully open to guests of the system (guest access). In addition to classes, consultations are expected to be held through the Microsoft Teams platform.

Each team within the Microsoft Teams platform represents one subject. Each student has insight only into the teams (subjects) he / she is following in the current year. After passing the exam in the subject, the student is no longer authorized to access it. Realized lectures and exercises at the university are recorded in their entirety and are all visible to students after lectures and exercises. Students view videos using the Microsoft Stream platform.

For the needs of the analysis, the platform was implemented at several physical locations, namely Belgrade, Novi Sad and Nis. The system also supports the possibility of access for students who access from domains that are not from the Republic of Serbia. Students who access the platform in this way are guests of this system and have a restrictive overview of the content in relation to the students from the

Republic of Serbia. Before the introduction of the state of emergency in the country, the university realized classes in the classical way with the use of amphitheaters and electronic classrooms. Each of these lectures involved the physical arrival of students at the university as well as the use of technical equipment by lecturers and students (computers, monitors, projectors, etc.). After the implementation of the Microsoft Teams platform, we directly reduce the cost of technical equipment.

The analysis of this paper required the assignment of more than 6000 students as well as 300 lecturers to different groups within the Faculty Information System as well as within the Microsoft Office 365 groups.

Students with previous computer knowledge and knowledge in the field of new technologies have created a very optimistic attitude towards the online way of knowledge transfer. Their performance and self-directed learning were directly affected by the use of e-platforms during the Covid-19 pandemic.

Proposed solution

In order for integration to be possible, in addition to all other external factors that can potentially affect the quality of video and audio material transmission, the most important item is certainly the Internet connection. In this case, the speed of the Internet connection of the lecturer and the listener is important. Based on the performed test, the obtained results are such that the largest number of listeners and lecturers is in the range of 60-80% of the quality of the Internet connection. The results of this test are shown in Table 1.

Table 1 – System performance
Табела 1 – Успешност система
Таблица 1 – Эффективность системы

Microsoft Service	Number of achievement points	Maximum number of points (100/100%)
Exchange Online	79	100
SharePoint Online	53	100
Microsoft Teams	72	100
Quality of Internet connection	68%	100%
SUM	204	300

We will primarily rely on the use of the Exchange Online service. Based on a test done on 6107 users, the result shows that the average latency is 30ms. This number indicates that users have been able to use the app without interruption for the past 30 days. SharePoint gives slightly worse results for a reason. The obtained result is the result of the use of Wi-Fi connection by the end users of the system and slightly worse quality of the upload and download stream. Compared to the SharePoint platform, the Microsoft Teams platform offers much better performance for end users. The platform itself is the most commonly used compared to all Microsoft platforms within the Microsoft Office365 package. This is also visible in test results with final results such that UDP latency is 50ms, UDP jitter 27ms and UDP packet loss 0.33%. Based on the test, information was obtained that 31% of users who use the Microsoft Teams platform spend more than 10 hours each week in meetings or lectures, Table 1. In this way, we come to the fact that the attendance of online classes is much higher compared to traditional classes. The fact is that these results are influenced by the flexibility of access to teaching and the reduction of costs for students studying in non-residential cities (Burcea & Marinescu, 2011). The obtained result is among the best in this part of Europe, taking into account the quality of the Internet in our country compared to the surrounding countries. The obtained results serve us to adjust the system and avoid possible unwanted problems in the following years of distance learning. The potential escalation of certain system problems can have a very negative impact on the overall learning system.

In addition to classic lectures and exercises, students use the 1-on-1 call option very often. One example of a 1 on 1 call is student and professor consultations. The average obtained on the basis of the test is such that 64% of conversations last more than 30 minutes. Based on this information, we gain insight into the fact that a large number of students use this option to develop projects in groups as well as mutual counseling. The amount of time spent on the platform in one week of lectures is visible in Figure 1. Based on the illustration, we can conclude that professors who teach in most cases use video and audio as well as screen sharing at the same time. This way of presenting creates a much greater interaction between students. Students are able to see some practical interactive examples in addition to listening to lectures.

Lecturers often use graphic boards during lectures in order to interact with the presented materials at the highest possible level. In addition to technology, the interaction is directly affected by the quality of knowledge transfer by the lecturer. The number of meetings organized

on the Microsoft Teams platform in the previous 30 days is shown in Figure 2.

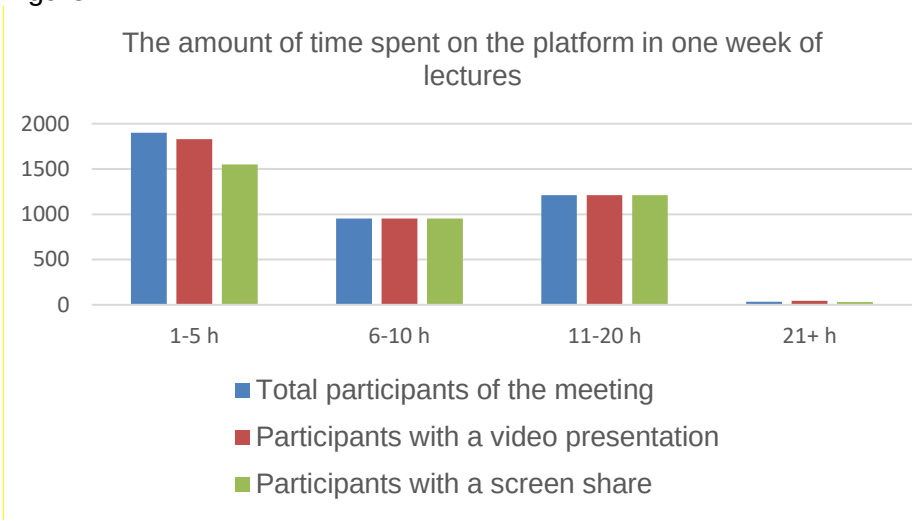

Figure 1 – The amount of time spent on the platform in one week of lectures
Слика 1 – Количина проведеног времена на платформи у једној недељи предавања
Рис. 1 – Количество времени, проведенного на платформе за одну неделю лекций

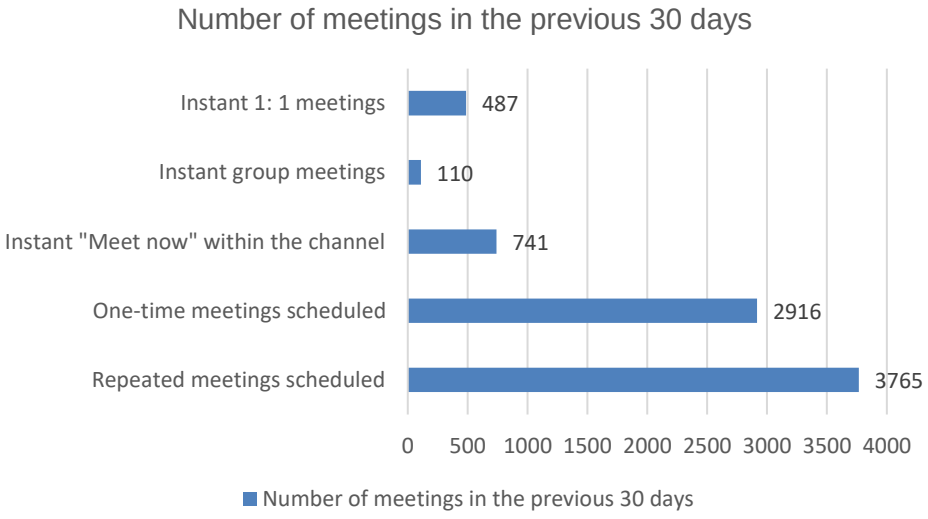

Figure 2 – Number of meetings in the previous 30 days
Слика 2 – Број састанака у претходних 30 дана
Рис. 2 – Количество встреч за предыдущие 30 дней

The use of the Microsoft Teams application has increased by 1368% since the university switched to online teaching. This is the information obtained based on the use of the previous 90 days.

Video and presentation materials can be accessed through the Files and Videos tabs on the Microsoft Teams platform. Each team / subject has an identical structure that contains the following elements:

- **Posts** – notifications sent to students as well as test results
- **Files** – page of items for storage of presentation materials
- **Class Notebook** – the ability to take notes by students and professors during and after lectures
- **Assignments** – tests created for the team / subject
- **Grades** – review grade students
- **Video materials** – view student videos using the Microsoft Stream application

Looking at the log files of the Microsoft Teams platform, we came to the conclusion that the largest number of users access the platform via computers with the Windows operating system, although a large number of system users have the ability to access via mobile phone. The time range of the graphs is 30 days. The distribution of licensed system users can be seen in Figure 3.

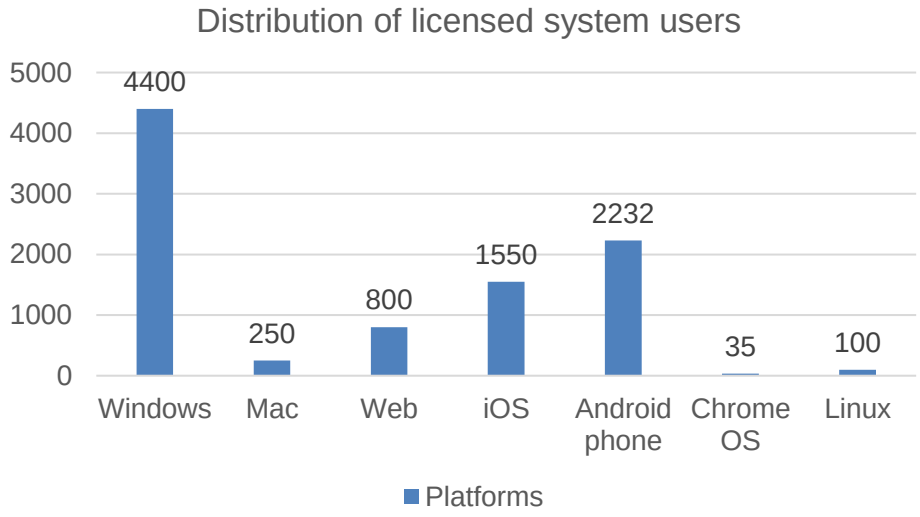

Figure 3 – Distribution of licensed system users
Слика 3 – Дистрибуција лиценцираних корисника система
Рис. 3 – Распределение лицензированных пользователей системы

It is important to note that students are allowed access from almost all existing operating systems, which offers students additional flexibility in terms of monitoring classes (Van Rousselt, 2021).

Technical presentation of the implementation of the proposed solution

The existing infrastructure made it possible to retrieve student information from the database. The information that was needed for the successful completion of the integration is the student's e-mail and the ID of the team in which the student is. Student information is automatically read from the database and sent in .csv format to the shared disk of the existing infrastructure. For this type of integration, a PowerShell script was used, which is run using a .bat file every hour. It is primarily necessary to create new student emails using the PowerShell environment. The initial password for all University students is their JMBG number. Changing all student passwords is enabled using the PowerShell script. The first step in developing an automated proposed solution is reflected in the creation of new student Microsoft Office 365 email addresses. The PowerShell script codes are shown in the next section of the paper.

```
$ErrorActionPreference="SilentlyContinue"
Stop-Transcript | out-null
$ErrorActionPreference = "Continue"

$LogTime = Get-Date -Format "dd-MM-yyyy_HH-mm-ss"
$LogName = "Path-to-.csv-file"+$LogTime+".txt"
Start-Transcript $LogName

$username = "username"
$password = ConvertTo-SecureString "password" -AsPlainText -Force

$psCred = New-Object System.Management.Automation.PSCredential -
ArgumentList ($username, $password)
Connect-MsolService -Credential $psCred
Import-CSV "Path-to-.csv-file" -delimiter ",”|Foreach-Object {
$userCheck = Get-MsolUser -UserPrincipalName $_.UserPrincipalName -
ErrorAction SilentlyContinue
    if($userCheck -ne $Null){
        $userName = $_.UserPrincipalName
        Write-Host "User already exists! E-mail of student is:
"$userName
    }else{
        Write-Host "User creation begins"
```

```
        New-MsolUser -UserPrincipalName $_.UserPrincipalName -
DisplayName $_.DisplayName -FirstName $_.FirstName -LastName $_.LastName
-UsageLocation "RS" -LicenseAssignment
"singimail:STANDARDWOFFPACK_IW_STUDENT"
        Set-MsolUserLicense -UserPrincipalName $_.UserPrincipalName -
AddLicenses "singimail:STANDARDWOFFPACK_STUDENT"

        Set-MsolUser -UserPrincipalName $_.UserPrincipalName –
StrongPasswordRequired $False
        Set-MsolUserPassword -UserPrincipalName $_.UserPrincipalName -
NewPassword $_.NewPassword
        Set-MsolUser -UserPrincipalName $_.UserPrincipalName -
PasswordNeverExpires $True
    }
}

Stop-Transcript
```

The mentioned script enabled the automation of creating emails after enrolling a student at the University. The script retrieves information from the existing Faculty Information System and creates new emails based on them. Since students will use a large number of Microsoft services, they need to be assigned the appropriate licenses. The licenses that are added to each student account are “A1 for students” and “A1 Plus for students”. The assigned licenses carry all the appropriate services for uninterrupted listening to online classes. The next step defines the automation of adding students to the appropriate teams selected through the eStudent platform.

```
$username = "username"

$password = ConvertTo-SecureString "password" -AsPlainText -Force

$psCred = New-Object System.Management.Automation.PSCredential -
ArgumentList ($username, $password)

Connect-MicrosoftTeams -Credential $psCred

Import-Csv " Path-to-.csv-file" -delimiter "," | foreach{Add-TeamUser -
GroupId $_.GroupId -user $_.email} -Verbose
```

The use of the script enabled the automation of adding new students based on their email address and the ID of the team in which it is necessary to enroll a new student.

Also, it was necessary to make a connection between the existing Faculty Information System and the Microsoft Office 365 platform. It was necessary to associate the ID numbers of all teams with all acronyms within the existing system. A link table has been created that contains this data and that greatly affects the security and execution speed of the existing scripts.

Demonstration of system upgrades on the existing infrastructure

When we look at the presence of students in online classes in relation to classical classes, we come to the conclusion that a larger number of students more regularly approached classes in online format. The statistics showing student attendance over a 30-day time range is shown in Figure 4.

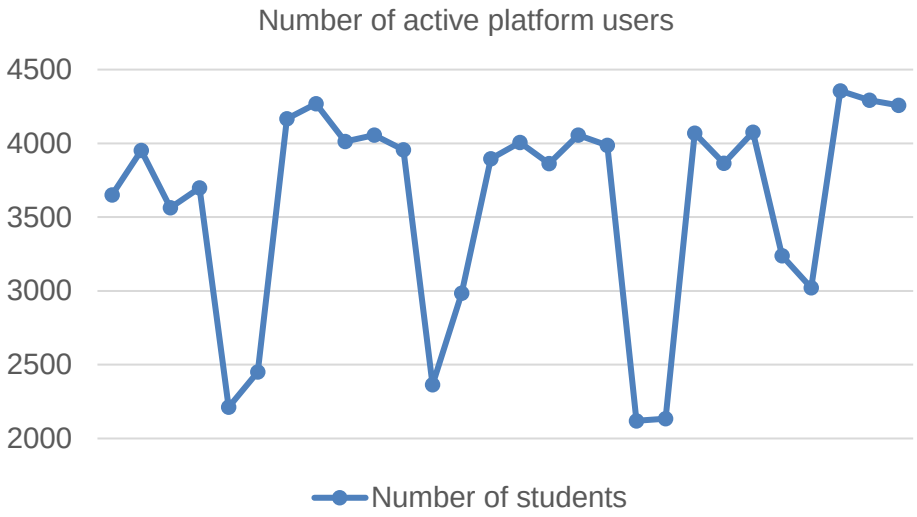

Figure 4 – Number of active users of the platform
Слика 4 – Број активних корисника платформе
Рис. 4 – Количество активных пользователей платформы

Based on the information from the system, we can conclude that on average every day there were 3973 students who joined the Microsoft Teams platform.

The interaction of students in relation to classical teaching is much greater. The statistics showing student interaction over a 30-day time range is shown in Figure 5. The illustration shows the relationship of

meetings held with the microphone on and the camera on. The recommendation to the lecturers is that their camera is turned on all the time while they are teaching, so that the interaction of the lecture is at the highest possible level.

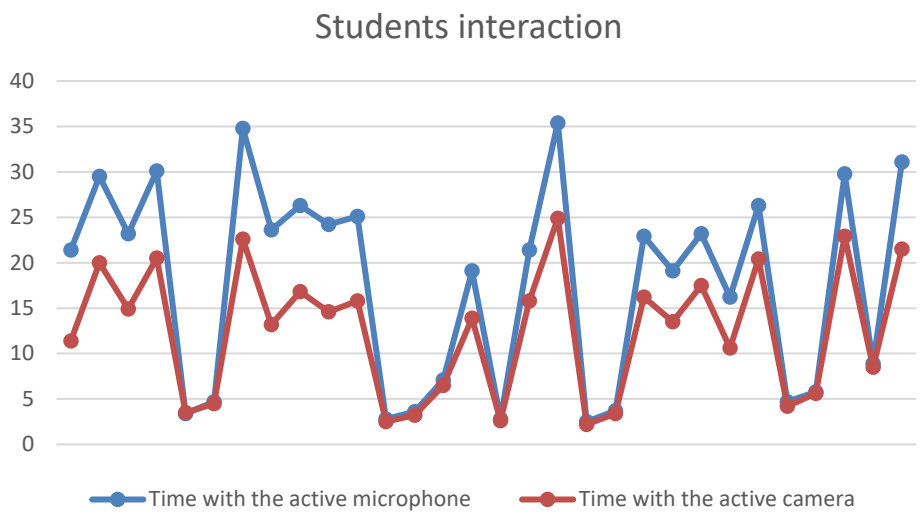

Figure 5 – Student's interaction
Слика 5 – Интеракција студената
Рис. 5 – Взаимодействие студентов

The implementation of such infrastructure has greatly reduced the physical attendance at the University. Based on a test done on active students accessing the Microsoft Teams platform, the result is that 83% of students do only remote access type access while the remaining 17% are university professors, assistants and administrative staff (Jenkins, 2020). The physical presence of students is shown in Figure 6.

The possibility of remote access to services directly affects the flexibility and ease of use of the service itself. The fact that 83% of users access the service remotely tells us that the access itself is greatly facilitated.

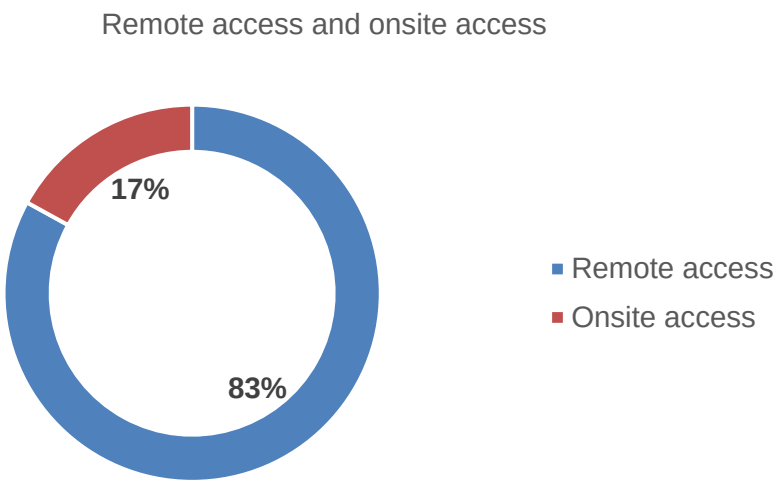

Figure 6 – Remote access and onsite access
Слика 6 – Удаљени приступ и онсите приступ
Рис. 6 – Удаленный доступ и доступ на месте

Recommendations, development plan and next steps

According to the current situation in the country and the world, the next step in the way of teaching is still unpredictable. For now, based on testing, it is considered that the next step will be the joint implementation of classical and online teaching. The combination of these two modes of knowledge transfer is called Blended learning (Pal & Vanijja, 2020). This way of teaching offers end listeners the opportunity to choose the format of teaching as desired, as well as the opportunity to review the recorded video materials after the lecture (Tucker, 2020).

Considering that this way of teaching is realized in one of these two ways, we come to a new concept which represents a hybrid model of teaching. This type of model offers the possibility of listening to lectures simultaneously in both classical and online ways (Tucker et al, 2016). In this case, it is up to the final listener to decide which way he wants to listen to the lecture. The hybrid model represents a synchronous type of communication while Blended learning represents an asynchronous type of communication (Cheng, 2014). Asynchronous types of communication can be used as a complement to the synchronous type of communication (Stevens, 2020).

Conclusion

Faced with a situation that has befallen the whole world, most educational institutions have been forced to switch to online teaching. The result of the test of working with students on the Microsoft Teams platform showed that by introducing a system for online teaching, we directly affect the improvement and quality of teaching. In addition to the impact on the teaching itself, a great influence was manifested in the segment of reducing the costs of educational institutions in various fields, such as the need for amphitheaters and electronic classrooms. The basic concepts of computer network security and protocols for secure communication between professors and students are covered. The main purpose of this paper is to raise awareness of the importance of teaching online. The increase in the number of users on the Internet leads to the fact that adapting to the online type of teaching should not be a big problem of adapting to end users.

The developed model can be used on all types of educational institutions, regardless of what activities the institution is engaged in. The authors plan to conduct further qualitative research on the effectiveness of teams as a computer-supported collaborative learning (CSCL) process. There are currently very few academic studies on this mode of knowledge transfer. Continuing the development of such services and joining learning systems (Learning management system, LMS) will contribute to more significant studies that will be thrown by testing the effectiveness of these teaching processes (Bond et al, 2019).

This way of knowledge transfer represents the future and it is very important to continue research on the impact of online knowledge transfer on both the quality and the economy of all countries. It is very important to test the systems in the context of the theory of education and in this case a social constructivist approach to shared learning can be applied. A further application of this model of online learning enables a larger sample that will contribute to better analysis and a better application of distance working modes worldwide. Academics can use this information as a basic idea to improve curricula. In the future, we plan to work on a semantic analysis of the system in order to create a better system for distance learning. In the meantime, other variables that affect learning will be fully expressed and may also be added in the future to explore correlations and impacts on the learning system. Future studies may explore these models more broadly as well as the sense and degree of influence of factors that may influence the learning model

(Archambault & Borup, 2020), (Batty, 2020), (Dabija et al, 2014), (Dellarocas, 2003).

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ПОДХОД К ОБУЧЕНИЮ В ОСЛОЖНЕННЫХ УСЛОВИЯХ ПЕРЕДАЧИ ЗНАНИЙ ВСЛЕДСТВИЕ ЧРЕЗВЫЧАЙНОЙ СИТУАЦИИ, ВЫЗВАННОЙ ПАНДЕМИЕЙ

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РУБРИКА ГРНТИ: 20.00.00 ИНФОРМАТИКА:
20.23.25 Информационные системы с базами,
12.00.00 НАУКОВЕДЕНИЕ:
12.21.35 Наука, культура и образование
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье представлена трансформация существующего классического подхода к обучению. Онлайн-платформа позволяет всем студентам, в том числе и студентам с ограниченными возможностями беспрепятственно посещать лекции и занятия. После лекций они могут просмотреть видеозапись и презентационные материалы. Основным преимуществом такого способа обучения является возможность посещать занятия, находясь в любой точке с помощью любого устройства, единственным условием является наличие Интернета.

Методы: Произведена полная интеграция с уже существующей информационной системой факультета. В статье описан новый подход к обучению и приведены ожидаемые преимущества онлайн-обучения. Приведем платформы, используемые в данной интеграции: Microsoft Azure, Microsoft Office 365 Admin, Microsoft Teams, Microsoft Stream и Microsoft SharePoint.

Результаты: Результаты тестирования работы со студентами показали, что внедренная система онлайн-обучения имеет непосредственное влияние на улучшение качество обучения.

Выводы: Учитывая все результаты, можно сделать вывод, что онлайн-обучение позволяет конечным слушателям полноценно усваивать знания во время лекций, а также они имееют возможность их повторного прослушивания.
Данной моделью может пользоваться неограниченное количество пользователей из всех учреждений, независимо от того, относится ли сфера деятельности этих учреждений к системе образования.

Ключевые слова: образование, онлайн-обучение, анализ обучения, Microsoft Teams, Microsoft Azure.

ПРИСТУП НАСТАВИ У УСЛОВИМА ОТЕЖАНОГ ПРЕНОСА ЗНАЊА УСЛЕД ВАНРЕДНОГ СТАЊА ИЗАЗВАНОГ ПОЈАВОМ ПАНДЕМИЈЕ

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ОБЛАСТ: информационе технологије
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У овом раду приказана је трансформација тренутног, класичног приступа настави. Онлајн платформа омогућава свим студентима, па и оним са хендикепом, да несметано прате наставу у термину предавања. Након тога, омогућено им је да прегледају видео и презентационе материјале. Главна предност оваквог начина предавања јесте могућност присуствовања настави са било које локације и са било ког уређајакоји је повезан на интернет конекцију.

Методе: Извршена је потпуна интеграција са већ постојећим факултетским информационим системом. Рад описује нови приступ настави и илуструје очекиване предности онлајн наставе. Платформе које су коришћене у овој интеграцији су: Microsoft Azure, Microsoft Office 365 Admin, Microsoft Teams, Microsoft Stream и Microsoft SharePoint.

Резултати: Резултат тестирања рада са студентима показао је да се увођењем система за онлајн реализацију наставе директно утиче на побољшање и квалитет наставе.

Закључак: Сагледајући све резултате може се доћи до закључка да прелазак на онлајн начин предавања омогућава крајњим слушаоцима свеобухватни пренос знања, као и његово поновно преслушавање. Овај модел је могуће користити на неограниченом броју корисника у свим институцијама, без обзира на њихову делатност.

Кључне речи: едукација, онлајн учење, анализа наставе, Microsoft Teams, Microsoft Azure.

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PULVERIZED RIVER SHELLFISH SHELLS AS A CHEAP ADSORBENT FOR REMOVING OF MALATHION FROM WATER: EXAMINATION OF THE ISOTHERMS, KINETICS, THERMODYNAMICS AND OPTIMIZATION OF THE EXPERIMENTAL CONDITIONS BY THE RESPONSE SURFACE METHOD

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FIELD: Environmental protection, Chemical engineering
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: In this study, we investigated the possibility of removing the organophosphorus pesticide malathion from water using a new adsorbent based on the biowaste of river shell shards from the Anodonta Sinadonta woodiane family, a material that accumulates in large quantities as waste on the banks of large rivers. Two adsorbents were tested - mechanically comminuted river shells (MRM) and mechanosynthetic hydroxyapatite from comminuted river shells (RMHAp).

Methods: The obtained adsorbents were characterized and tested for the removal of the organophosphorus pesticide malathion from water. In order to predict the optimal adsorption conditions using the Response Surface Method (RSM), the authors investigated the influence of variable factors (adsorption conditions), pH values, adsorbent doses, contact times, and temperatures on the adsorbent capacity.

Results: The best adsorption of malathion was achieved at mean pH values between 6.0 and 7.0. The adsorption data for malathion at 25, 35, and 45 °C were compared using the Langmuir, Freundlich, Dubinin-Radushkevich (DR), and Temkin isothermal models, as well as pseudo-first order, pseudo-second order and Elovic kinetic models for modeling adsorption kinetics. The maximum Langmuir adsorption capacity for MRM and RMHAp at 25 °C was 46,462 mg g^{-1} and 78,311 mg g^{-1}, respectively.

Conclusion: The results have showed that malathion adsorption on both adsorbents follows the pseudo-second kinetic model and the Freundlich isothermal model. The thermodynamic parameters indicate the endothermic, feasible, and spontaneous nature of the adsorption process.

Key words: removal, adsorbent, kinetics, isotherms, optimization, pesticide, water, river shells.

Introduction

The development of technology undoubtedly contributes to the development of society; however, it also causes environmental pollution. A distinct surge in the world's population and an increase in food needs condition the development of intensive agricultural production based on the use of inputs to overcome factors that limit production such as insects, fungi, weeds, and land scarcity (Kamga, 2019). The usage of pesticides is intended to combat animals and plants that are harmful to crops, thus enabling increased yields and ensuring the sustainability of

the human population. Non-selective use of pesticides in agricultural activities leads to the pollution of surface and underground water accumulations. Due to its potential danger to health by entering the food chain for humans and animals, pesticide pollution has reached alarming proportions. (Chatterjee et al, 2010)

Pesticides are ecologically very important because of their high toxicity to living organisms, including humans; the toxicological profile of this pollutant poses a potential risk to the environment and public health (Kamga, 2019). According to numerous studies, many insecticides such as DDT, deildrin, heptachlor, and aldrin bioaccumulate in blood, milk, and tissues and are also found in food products (Singh et al, 2010).

It has been confirmed that patients with acute organophosphate poisoning suffer from problems such as vomiting, nausea, miosis, excessive salivation, blurred vision, headache, dizziness, and disturbances of consciousness (Singh et al, 2010). In the case of malathion, which is one of widely used organophosphorus pesticides, almost all the observed effects occur due to its active metabolite malacon (Singh et al, 2010) on the nervous system or gives secondary effects to its primary action.

Malathion is slowly absorbed through the skin, but is more rapidly and efficiently absorbed via ingestion. Once they are absorbed, phosphorothioates such as malathion are metabolically activated to the “oxon” forms which have greater toxicity than the parent insecticide. The metabolism of malathion leads to the formation of malathion monocarboxylic acid, malathion dicarboxylic acid, dialkyl phosphate metabolites, and other metabolites (Bouchard et al, 2003).

In recent years, research on the removal of pollutants from water has been intensified, based on the phenomenon of adsorption, among which the removal of pesticides from water occupies a special place. We have a large number of potentially highly effective adsorbents for removing pesticides from water such as activated carbon (Kamga, 2019; Ohno et al, 2008; Hameed et al, 2009), but the high price of activated carbon limits its mass use in many poor countries. Therefore, the attention of researchers is increasingly focused on finding a cheap, environmentally friendly, and highly efficient adsorbent to solve this problem. Various adsorbents such as agricultural by-products, waste materials, cheap minerals and biomass have been used to remove various pollutants from wastewater (Chatterjee et al, 2010; Pantić et al, 2019; Bajić et al, 2013; Stevanović et al, 2020; Karanac et al, 2018; Perendija et al, 2021).

Malathion, an organophosphorus highly selective insecticide, is widely used in agriculture worldwide (Chatterjee et al, 2010), primarily in the control of insects, including mosquitoes, aphids, grass insects, and many other parasites of vegetable crops and fruits. Until today, the removal of malathion from wastewater has not been studied in detail and only a few studies are available in this regard (Chatterjee et al, 2010).

The shards of river shells are waste that burdens a large number of beaches and the banks of rivers, seas, and lakes. They also appear as waste after use in human nutrition. The aim of this paper is to apply shellfish as a cheap, widely available, environmentally friendly material for removing organophosphorus pesticides from water. In this way, we get a double benefit: we use waste that burdens the shores of different watercourses to remove pollutants that load the water and cause negative effects on life and health of humans and animals as well as on the environment in general.

Materials and methods

Materials

A large number of different chemicals were used during the research. Bearing in mind that the properties of the adsorbent, as well as the research results largely depend on the purity of the reagent, high purity chemicals were used:

- 5% hydrogen peroxide solution - H_2O_2 (Sigma-Aldrich, PA),
- concentrated nitric acid HNO_3 (Fluka, ultrapure) - used for digestion of shells in order to determine the elemental composition and adjust the pH level,
- concentrated phosphoric acid H_3PO_4 (Sigma-Aldrich, PA),
- sodium hydroxide - NaOH (Sigma Aldrich, PA) - used to adjust the pH of the solution in the adsorption process and titration during the synthesis of adsorbents,
- 96% ethyl alcohol (Sigma Aldrich, PA) - used in the washing of adsorbents,
- deionized water (resistance of 18 MΩ cm) - used for sample preparation and dilution of the solution,
- malathion, 60% technical solution (Galenika-Fitofarmacija) – used for performing an adsorption experiment (as 20 mg dm^{-3} concentration solution),
- biowaste of shellfish from the genus *Anodonta Sinadonta woodiane*, collected from the banks of the Tisza River.

Synthesis of adsorbents

During the research, two types of adsorbents based on river shell shards were synthesized and tested in the process of adsorption:

1. shells, washed, mechanically ground, sieved, washed, and dried in a vacuum oven - clean shells (MRM), and
2. fish carp scales chemically modified by converting calcium carbonate to hydroxyapatite by mechanosynthesis (RMHAp).

The shards of the *Anodonta Sinadonta woodiane* river shell were thoroughly washed and rinsed in distilled water, air-dried for 24 h, ground in a steel mill for crushing sediments and sifted into a 0.5 -1 mm granulation powder. The shell powder was washed in vacuo with deionized water, ethyl alcohol and dried in vacuo for 24 h at 110 ^{o}C to give the first MRM adsorbent (mechanically prepared river shells).

In the stainless steel vessel of a planetary ball mill (Retsch PM100 CM), 10 g of MRM was mixed with 11.23 ml (18.92 g) of concentrated H_3PO_4 - $CaCO_3$ ratio: $H_3PO_4 \rightarrow$ Ca / P = 1.67; zirconium beads were added in ratio 20:1 of the bead mass to a sample and the mixture was treated in a ball mill for 10 h at 500 grp for further mechanosynthesis. After the treatment in a ball mill, the obtained mixture was washed copiously in vacuo with deionized water to remove unreacted parts of the acid and dried in vacuo for 24 h at 110 ^{o}C to obtain a second RMHAp adsorbent (hydroxyapatite).

Material characterization methods

The synthesized adsorbents were characterized by FTIR, XRD, SEM and EDS techniques. The elemental composition was determined by a chemical elemental analyzer, the content of individual elements was determined by dissolving in acids and measuring the content on a plasma mass spectrometer with a plasma-coupled plasma ICP-MS system Agilent 7500C (Agilent Technologies, Inc.) and an atomic adsorption spectrometer. The concentration of malathion before and after adsorption was determined using a gas chromatograph (GC) equipped with a flame ionization detector (FID) - Varian 3400 with FID operating system. The specific surface area of the adsorbent, the specific pore volume, and the pore diameter were determined by the BET method of adsorption / desorption in a stream of nitrogen at 72.4 K, using a gas sorption analyzer Micromeritics ASAP 2020MP v 1.05 H. The infrared Fourier transform spectrum (FTIR) was recorded in the transformation mode between 400 and 4000 cm-1 at a resolution of 4 cm-1 using an infrared (IR) spectrometer with Fourier transformation (FT) - Nicolet iS 50

manufactured by Thermo Scientific. The adsorbents morphology was observed using Tescan Mira 3 FEG scanning electron field microscopy (FESEM). The morphological structure was determined by x-ray diffraction, XRD, using an ENRAF NONIUS FR590 XRD (Bruker AKSS, MA, USA) diffractometer with Cu Ka 1,2 radiation and a step / scan time regime of 0.05 / 1 s. The pH value of the zero charge point (pHPZC) of adsorbents was determined by the "drift" method (Gao et al, 2009).

Malathion adsorption research

Adsorption experiments were performed in a batch system where the initial concentration of malathion solution was fixed Co = 20.32 mg L^{-1}, and the adsorbent dose was varied from 100 to 1000 mg L^{-1}. In order to examine the pH value influence on the adsorption process, the pH value was varied from 4.0 to 10.0. Thermodynamic and kinetic adsorption experiments were performed at temperatures of 25, 35 and 45 ^{o}C, and the adsorption process was monitored in a time interval of 10 to 180 minutes. The amount of adsorbed molecules was calculated as the difference between the initial and equilibrium concentration.

The adsorbent capacity was calculated in accordance with Eq. (1):

$$q = \frac{C_{\mathrm{i}} - C_{\mathrm{f}}}{m} V \tag{1}$$

where q is the adsorption capacity in mg g^{-1}, C_{i} and C_{f} are the initial and final malathion concentrations in mg L^{-1} (μg L^{-1}), respectively, V is the volume of the solution in L, and m is the adsorbent mass, expressed in g.

Kinetic studies

The study of kinetics provides an insight into a possible mechanism of adsorption along with the reaction pathways. The adsorption data were analyzed by linear, non-linear least-squares and graphic methods in the form of pseudo-first, pseudo-second-order (Lagergreen) and second order models (Table 1).

Diffusion models such as Weber-Morris, Dunwald-Wagner model, and Homogenous Solid Diffusion Model (HSDM) were used for modeling diffusional processes/limiting step of the overall process (Table 2) (Budimirović et al, 2017; Taleb et al, 2015; Taleb et al, 2019).

Table 1 – Kinetic model equations
Таблица 1 – Уравнения кинетических моделей
Табела 1 – Једначине кинетичких модела

Kinetic model	Nonlinear form	Model parameters	Equation
Pseudo-first-order equation	$q = q_e(1 - e^{-k_1 t})$	k_1- pseudo first-order rate constant, (min^{-1}) q_e- adsorption capacity at time t, (mg g^{-1}) q- adsorption capacity, (mg g^{-1}) t - time, (min)	(2)
Pseudo-second order equation (*Lagergreen*)	$q = \frac{t}{\frac{1}{k_2 q_e^2} + \frac{t}{q_e}}$	k_2 - pseudo-second order rate constant, (g mg^{-1} min^{-1})	(3)
Second order	$q = \frac{t}{\frac{1}{k_2 q_e^2} + \frac{t}{q_e}}$	k_2 - second order rate constant, (L mg^{-1} min^{-1})	(4)

Table 2 – Equations of the diffusion kinetic models
Таблица 2 – Уравнения диффузионных кинетических моделей.
Табела 2 – Једначине дифузионих кинетичких модела

Kinetic model	Nonlinear form	Equation
Weber-Morris	$\boldsymbol{q = k\sqrt{t} + C}$	(5)
Dunwald-Wagner model	$\frac{q}{q_e} = 1 - \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}exp[-n^2 K\, t]$ $log\left(1 - \left(\frac{q}{q_e}\right)^2\right) = -\frac{K}{2.303}t$	(6)
Homogenous Solid Diffusion Model (HSDM)	$\frac{\partial q}{\partial t} = \frac{D_s}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial q}{\partial r}\right)$ $\frac{q}{q_s} = 1 + \frac{2R}{\pi\, r}\sum_{n=1}^{\infty}\frac{(-1)^n}{n}\sin\frac{n\pi r}{R}exp\left[\frac{-D_s\, t\, \pi^2\, n^2}{R^2}\right]$	(7)

The activation energy for arsenate adsorption was calculated using Arrhenius (Eq. 8):

$$k` = k_0 \exp\left[\frac{-E_a}{RT}\right] \quad 8)$$

where k' (g mg^{-1} min^{-1}) is the pseudo-second order rate adsorption constant, k_0 (g mmol^{-1} min^{-1}) is the temperature independent factor, E_a (kJ mol^{-1}) is the activation energy, R (8.314 J mol^{-1} K^{-1}) is the gas constant, and T (K) is the adsorption absolute temperature. A plot of ln K' versus 1/T gave a straight line with a slope $-E_a$/R from which the activation energy was calculated.

Isotherm models

The equilibrium adsorption data were fitted by the isotherm models Langmuir, Freundlich, Temkin, and Dubinin-Radushkevich isothermal models (Karanac et al, 2018).

The Langmuir equation is based on the assumption that the point of maximum adsorption corresponds to a saturated mono-layer of adsorbate molecules on the adsorbent surface - where the energy of adsorption remains constant and no transfer of the adsorbate in the surface plane occurs.

The Freundlich sorption isotherm, widely and reliably utilized as a mathematical determining expression, allows for a calculation encompassing surface heterogeneity and exponential distribution of active sites as well as their respective energies (Karanac et al, 2018).

Temkin conceived this equation for subcritical vapors in micropore solids where the adsorption process follows a pore filling mechanism onto an energetically non-uniform surface.

The Temkin isotherm is based on the assumption that the decline of the heat of sorption as a function of temperature is linear rather than logarithmic. The Dubinin-Radushkevich model states that the adsorption capacity depends on the adsorbed amount on the surface of the material, differently from the Langmuir model." (Karanac et al, 2018).

The equations of adsorption isotherms models are presented in Table 3.

Table 3 – Adsorption isotherms equations
Таблица 3 – Уравнения изотермы адсорбции
Табела 3 – Једначине адсорпционих изотерми

Isotherms	Nonlinear form	Model parameters	Equation
Langmuir	$q_e = \frac{q_m K_L C_e}{1 + K_L C_e}$	q_e- adsorption capacity at th eequilibrium, (mg g^{-1}) q_m- maximum adsorption capacity, (mg g^{-1}) K_L- Langmuir equilibrium constant, (L mg^{-1}) C_e- metal ion concentration at the equilibrium (mg L^{-1})	(9)
Freundlich	$q = K_F C^{1/n}$	*K_F- Freundlich equilibrium constant, (mg g^{-1})(L mg^{-1})$^{1/n}$* *n- Freundlich equilibrium constant (intensity of the adsorption or surface heterogeneity)*	(10)
Temkin	$q_e = \frac{RT}{b}\ln(AC_e)$	A -Temkin isotherm equilibrium binding constant (L g^{-1}) b - Temkin isotherm constant R-universal gas constant (8.314J $mol^{-1}K^{-1}$) T-Temperature at 298K.	(11)
Dubinin-Radushkevich	$q_e = q_m exp\left(-B(RT)^2\left(ln\left(1+\frac{1}{C_e}\right)\right)^2\right)$		(12)

Thermodynamic studies

The feasibility of the experimental data obtained from the adsorption studies were analyzed through the thermodynamic investigation. The parameters of free energy change (*ΔG°,* kJ/mol), enthalpy change (*ΔH°*, kJ mol^{-1}), and entropy change (*ΔS°*, J mol^{-1} K^{-1}) were calculated using the Van't Hoff equations (13) and (14) (Karanac et al, 2018):

$$\Delta G^0 = -RT\ln(b) \quad (13)$$

$$\ln(b) = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{(RT)} \quad (14)$$

The separation factor (R_L) is in relation to the Langmuir isotherm and it is used to assess adsorption feasibility on the given adsorbent. It is calculated using the next Eq (15):

$$R_L = \frac{1}{(1+bC_0)} \quad (15)$$

where C_0 (mol dm^{-3}) is the initial adsorbate concentration, b ($dm^3\,mol^{-1}$) is the Langmuir constant. The value of R_L points out to the isotherm type: irreversible ($R_L = 0$), favorable ($0 < R_L < 1$), linear ($R_L = 1$), unfavorable ($R_L > 1$).

Statistical analysis of the experimental data

All adsorption experiments were repeated three times and the mean values were taken for further processing and modeling. The obtained results were analyzed using the normalized standard deviation Δq (%) which is calculated using the following equation:

$$\Delta q(\%) = \sqrt{\sum \frac{\left[\left(q_{exp} - q_{cal}\right)/q_{exp}\right]^2}{N-1}} x100 \quad (16)$$

where q_{exp} and q_{cal} are the experimental and calculated values of adsorbed malathion, and N is the number of data used in the analysis. The maximum deviation is <3%, which is an experimental error. Standard errors for isothermal, kinetic, and thermodynamic parameters were determined using the commercial software Microcal Origin 8.0 (Pantić et al, 2019).

In order to confirm the adsorption model that best corresponds to the experimental data, they were analyzed by the ANOVA variance analysis, using the F value together with the values of the correlation coefficient (R) from the regression analysis. (Pantić et al, 2019; Bajić et al, 2019)

Optimization of the experimental adsorption conditions

The optimization of the adsorption conditions was performed using the RSM (Surface Response Methodology) method. Classical adsorption optimization usually involves examining the impact of each variable separately. However, it is difficult to predict optimal reaction conditions based on such results due to possible interactions between different independent variables involved in adsorption reactions. (Pantić et al, 2019; Bajić et al, 2019) Recently, various statistical programs have been used that are useful to help establish the design of the experiment. Using response surface methodology (RSM) as a mathematical function, it is possible to examine the individual and interactive influences of different variables in relation to different predictors. In that way, we get the optimal conditions that are needed to get the best results. (Pantić et al, 2019) In addition, it has been proven that the central composition design (CCD) and the Bok-Behnken design (BBD) are efficient designs of RSM models in optimizing the adsorption process. (Pantić et al, 2019) In this study, the

synthesized modified adsorbent RMHAp was used to remove malathion from water. The adsorption process is optimized by numerical and graphical optimization methods using the Bok-Behnken design. We used the design with four factors (input variables) and three levels of values in which 29 experiments with five replications in the central point were performed. The capacity of the adsorbent was taken as a response. Extremely optimized conditions were confirmed by additional experimental testing. The conditions of the adsorption experiment are given in Table 4.

Table 4 – An experimental malathion adsorption plan was performed using a four-factor BBD design with three levels of value

Таблица 4 – Экспериментальный план адсорбции малатиона с использованием четырехфакторного BBD моделирования с тремя уровнями величин

Табела 4 – Експериментални план адсорпције малатиона добијен коришћењем четворофакторског ББД дизајна са три нивоа вредности

Ordinal number	A Dose ads. (mg/L)	B t (min)	C pH	D T(°C)	*Response* q_e (mg g^{-1})
1.	1000	95	7	45	14.1
2.	1000	95	7	25	12.6
3.	100	95	4	35	30.11
4.	550	95	4	45	12.05
5.	1000	180	7	35	15.06
6.	100	95	10	35	27.4
7.	1000	95	10	35	6
8.	550	95	10	25	9.38
9.	550	95	7	35	24.3
10.	550	10	7	25	13.2
11.	100	95	7	45	71.2
12.	100	180	7	35	81.15
13.	550	95	4	25	10.1
14.	550	10	4	35	8
15.	550	95	10	45	13.1
16.	100	10	7	35	27.3
17.	550	180	7	25	28.5
18.	550	10	7	45	14
19.	550	95	7	35	24.3
20.	1000	10	7	35	5.21
21.	550	180	7	45	28.75
22.	550	95	7	35	24.3
23.	550	180	10	35	13.8
24.	550	95	7	35	24.3
25.	550	95	7	35	24.4
26.	1000	95	4	35	6.75
27.	550	180	4	35	15.11
28.	100	95	7	25	64.4
29.	550	10	10	35	5.6

Results and discussion

Physical and chemical characterizations of adsorbents

The elemental composition of shellfish shards is given in Table 5. This elemental composition is similar to that of other authors (Vei et al, 2018; Buasri et al, 2013) and indicates that shellfish shards are mostly composed of calcium carbonate-based minerals (calcite and argonite) and the organic part of chitin that connects calcite structures. The composition of shells also includes various microelements - ions, which replace Ca^{2+} in the structure of calcium carbonate and are incorporated into the shell during its formation. The availability and rate of bioaccumulation of these ions is a function of environmental and biological factors. Thus, different habitats, contamination - the presence in the water of different ionic species, different stages of shell development can represent different patterns of metal incorporation.

Table 5 – Concentrations of major, minor and trace elements obtained in this study using the ICP-AES and ICP-MS methods
Таблица 5 – Концентрации основных, второстепенных и микроэлементов, полученных в данном исследовании с помощью методов ICP-AES и ICP-MS.
Табела 5 – Концентрације главних, споредних и микроелемената у траговима добијене у овом истраживању применом методе ИКП-АЕС и ИКП-МС

Element ICP-AES Method	Ca (wt %)	Fe (wt %)	Mg (wt %)	Si (wt %)	Na (wt %)	Mn (μg g^{-1})
	34.1	0.003	0.104	0.004	0.182	30.4
Element ICP-MS Method	Cd (μg g^{-1})	Co (μg g^{-1})	Cu (μg g^{-1})	Ni (μg g^{-1})	Pb (μg g^{-1})	Zn (μg g^{-1})
	0.094	0.079	31.2	2.01	3.09	21.5

The analyzed shards of the river shell *Anodonta Sinadonta woodiane* are composed of two polymorphs of calcium carbonate: calcite and aragonite, with calcite being the dominant form. Recent studies have found that the dominant $CaCO_3$ polymorph may be temperature dependent - aragonite deposition is at high temperature and calcite deposition is at low temperature (Kuklinski and Taylor, 2009; Ramajo et al, 2015; Krzeminska et al, 2016). The confirmation of the composition of the shells can also be seen on the spectrum of energy dispersive spectrometry (Figure 1) where the main building blocks are observed before (a) and after the modification of the shells (b). After modification, we notice the presence of phosphorus in the adsorbent, which confirms the transition of calcium carbonate to hydroxyapatite.

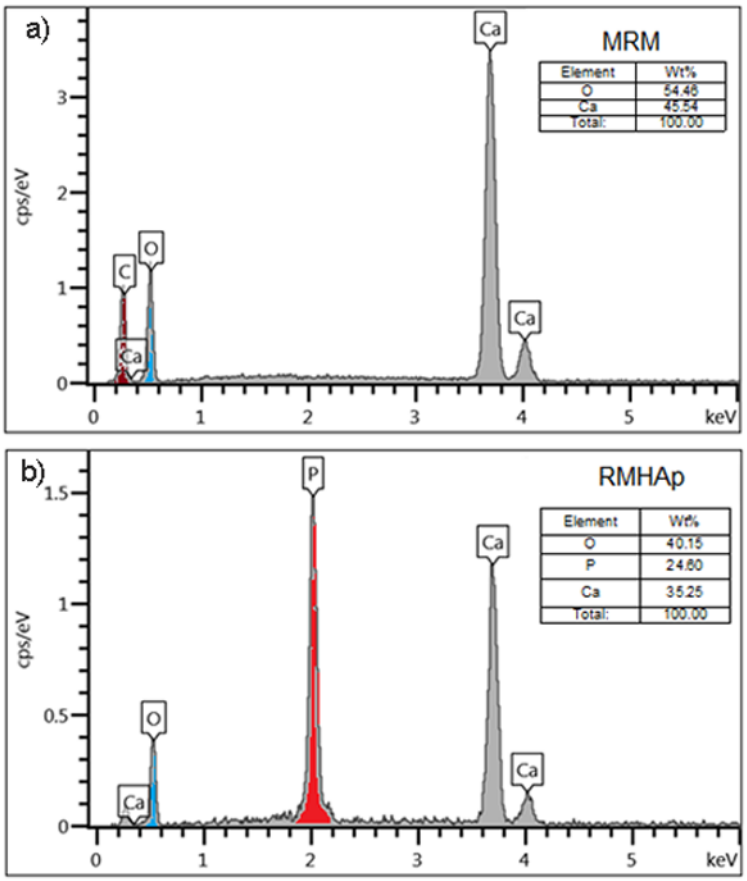

Figure 1 – EDS spectrum of shellfish powder before (a) and after modification (b)
Рис. 1 – Спектр EDS порошка раковины до (а) и после модификации (б)
Слика 1 – ЕДС спектар праха шкољке пре (а) и након модификације (б)

In the scanning electron microscopy photographs (Figure 2) with different magnifications, we can clearly see the lamellar structure of the shell. The lamellae consist of materials based on calcium carbonate (calcite and argonite) with a thickness of about 1 μm and with cavities between the lamellae with a diameter of about 50 to 100 nm. They are interconnected by organic polymer chitin; nanopores are observed on the lamellae surface.

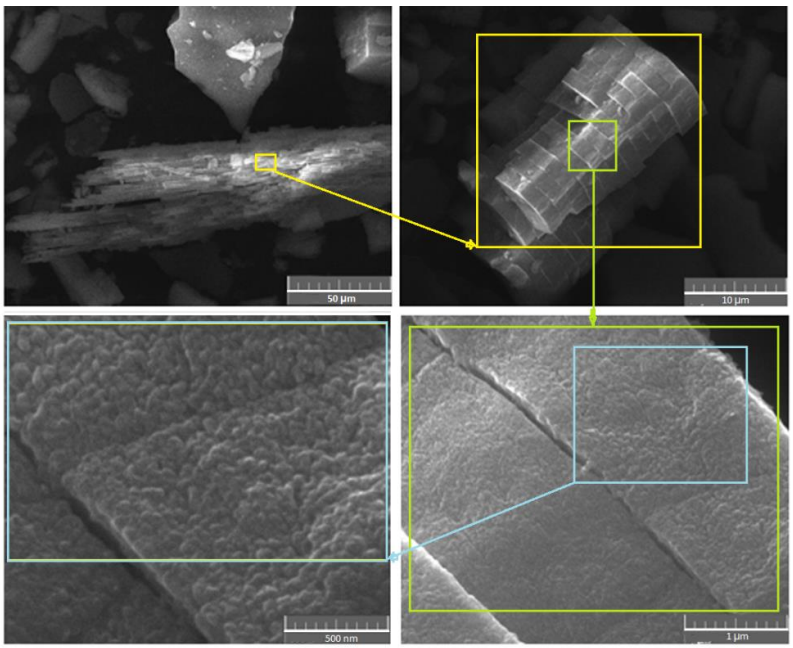

Figure 2 – SEM representation of mechanically prepared shells at different magnifications
Рис. 2 – СЭМ-изображение механически подготовленных раковин при различном увеличении
Слика 2 – СЕМ приказ механички припремљених шкољки при различитим увећањима

After mechanosynthesis, the lamellar structure derived from calcium carbonate is lost and we get the granular morphology of hydroxyapatite, presented in Figure 3. Electron scanning microscopy images showed the presence of rounded HAp microparticles in isolated and agglomerated forms. Based on the observations, HAp particles can be considered as microspheres whose crystal size is well below 1 µm.

The physical properties of the adsorbent, the specific surface area, the pore volume and the zero charge point are given in Table 6. The change in the pH_{PZC} value occurred under the influence of the change in the surface properties of the adsorbent due to modification (Table 6). At pH $<pH_{PZC}$, negatively charged species participate in electrostatic attraction with a positively charged adsorbent surface and vice versa, at pH> pH_{PZC}, electrostatic repulsion is a major factor leading to low adsorption efficiency.

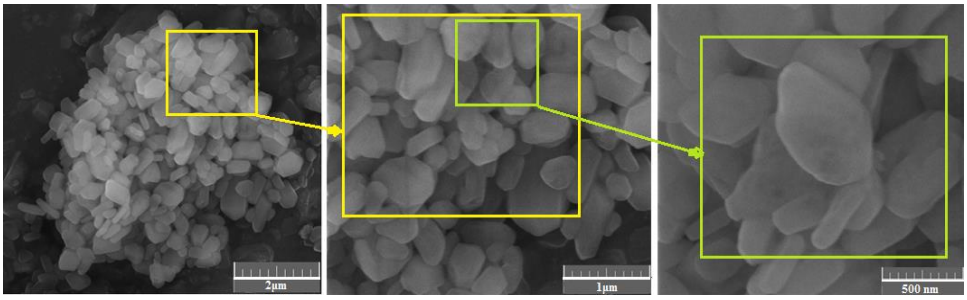

Figure 3 – SEM representation of the shells modified by mechanosynthesis at different magnifications
Рис. 3 – СЭМ-изображение раковин, модифицированных механосинтезом, при различном увеличении
Слика 3 – СЕМ приказ механосинтезом модификованих шкољки при различитим увећањима

Table 6 – Physical properties of MRM and RMHAp adsorbents
Таблица 6 – Физические свойства адсорбентов MRM и RMHAp
Табела 6 – Физичке карактеристике MRM и RMHAp адсорбената

Adsorbent	Specific surface area ($m^2\ g^{-1}$)	Pore volume (cm^3g^{-1})	Mean pore diameter (nm)	pH_{PZC}
MRM	2,58	0,096	6,7	7,2
RMHAp	1,95	0,088	9,18	7,05

Figure 4 shows the FTIR spectra of both adsorbents (MRM and RMHAp) before and after the adsorption of malathion from aqueous solution. In the spectrum a, the characteristic peaks at 710, 856 and 1460 cm^{-1} indicate the carbonate group in the sample which confirm that the sample contains $CaCO_3$. In addition, small infrared absorption spectra are shown at ~ 1790, and ~ 2874 cm^{-1} and have been attributed to regimens of combining different ranges of CO_3^{2-} (Khiri et al, 2016). The spectrum at ~ 1083 cm^{-1} is related to the C – O tensile vibrations as CO_2 adsorbed on the CaO surface (Khiri et al, 2016).

The FTIR spectrum (c) of the RMHAp adsorbent showed pronounced peaks at 560 cm^{-1} corresponding to the symmetrical bending regime of PO_4^{3-} and 1064 cm^{-1} corresponding to the asymmetric stretching regime of the PO_4^{3-} group corresponding to the vibrational structures of hydroxyapatite (Khiri et al, 2016). The large peak in Figure 4 in the spectrum a and a smaller peak in the spectrum c at 1460 cm^{-1} represent carbonate (CO_3), which is more pronounced before

mechanosynthesis, i.e. before the conversion of calcium carbonate into hydroxyapatite.

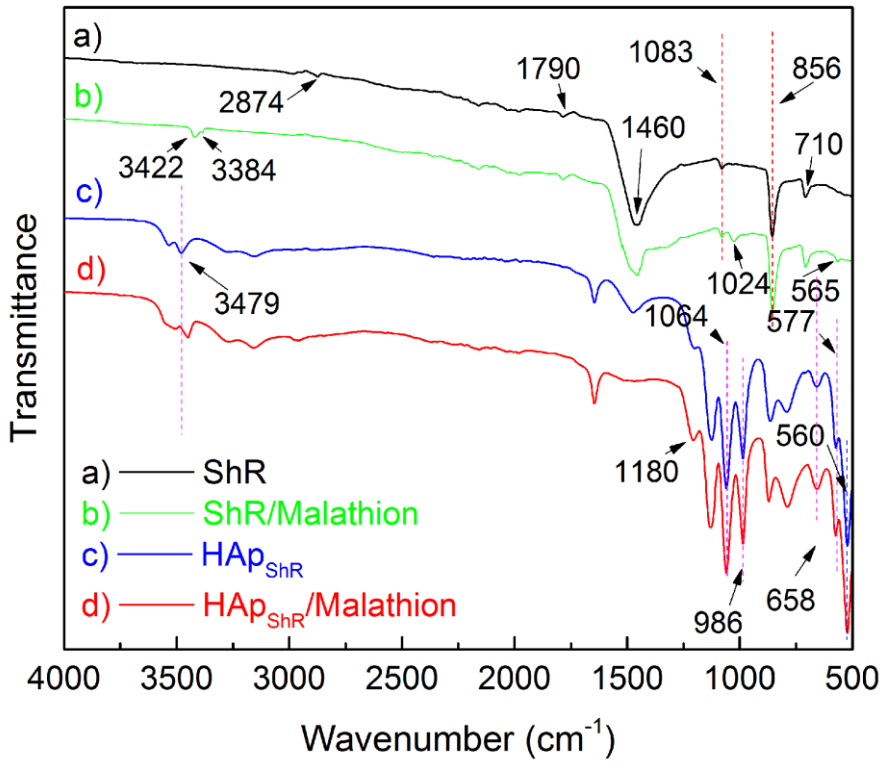

Figure 4 – FTIR spectrum of shellfish shards and modified shards before and after the adsorption of malathion from aqueous solution

Рис. 4 – FTIR-спектр осколков раковин и модифицированных осколков до и после адсорбции малатиона из водного раствора

Слика 4 – FTIR спектар љуштура шкољки и модификованих љуштура пре и након адсорпције малатиона

The characteristic vibration peaks of shell dust before and after modification with a comparative review by other researchers are given in Table 7.

Table 7 – FTIR shell powder vibration mode before and after mechanosynthesis (MRM and RMHAp) and references
Таблица 7 – FTIR режим вибрации порошка раковины до и после механосинтеза (MRM и RMHAp) и ссылки
Табела 7 – FTIR режим вибрација праха шкољке пре и после механосинтезе (MRM и RMHAp) и референце

	Vibration frequency (cm^{-1})			
	Our research FTIR	(Khiri et al, 2016)	(Salma et al, 2010)	(Islam et al, 2013)
Symmetrical deformation CO_3^{2-}	710	708		706
Asymmetric deformations CO_3^{2-}	856, 1460	855, 1454		857, 1455
Symmetric stretching vibration CO_3^{2-}	1083	1082		1082
CO_3^{2-} deformations	1790	1786		1794
PO_4^{3-} bending	560	565	560, 599	
PO_4^{3-} stretching	1064	1024	1046	
CO_3^{2-} group	1460	1454	1424	

After sorption of malathion (spectra b and d) on both adsorbents, changes were observed in the appearance of new peaks, decrease in their intensity as well as in their disappearance and displacement.

The diffraction analysis (XRD) results showed that the composition of the river shell (spectrum a) mainly consists of two forms of CaCO3, primarily calcite as shown by the diffraction peak at 2θ about 29.52, 39.56, 43.27, 47.6, and 48.63 (Wei et al, 2018) and argonite (Islam et al, 2013). Other minerals are present in smaller quantities as a consequence of the uptake of these minerals from the water during shell formation. The XRD spectrum of synthesized HAp also shows relatively high intensities and sharp peaks in the range of 23–39 (about 25.80 and 32.90 (Skwarek et al, 2014) corresponding to (hkl) indices) at (002) and (300), and lower peak intensities in the range of 40–39. 60, which is consistent with the formation of the lower crystal structure of HAp.

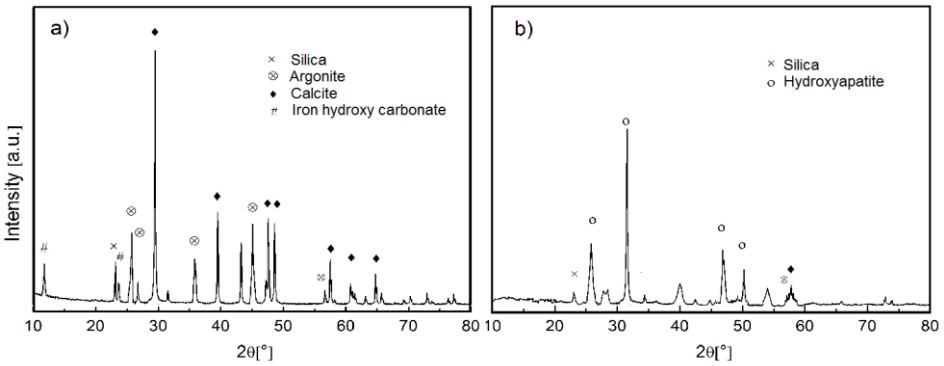

Figure 5 – X-ray diffraction analysis (XRD) spectrum of shellfish shards before (a) and after modification by mechanosynthesis (b)
Рис. 5 – Спектр рентгеновского дифракционного анализа (XRD) осколков раковин до (а) и после модификации механосинтезом (б)
Слика 5 – Спектар дифракционе анализе помоћу X-зрака (XRD) љуштура шкољки пре (а) и након модификације механосинтезом (б)

Influence of the solution pH on adsorption

The influence of the pH value on the system is manifested through surface tension, surface properties, degree of ionization of groups present on the surface of the adsorbent, as well as through the speciation of ions in aqueous solution at a certain pH value.

The pH effect on malathion removal is presented in Figure 6. As mentioned above, malathion retention depends on the nature of the adsorbent. Removal by RMHAp adsorbent is greater than removal by MRM. Similarly to the Saib study (Bouchenafa-Saib et al, 2014), the pH value of 6 appears to be optimal for malathion sorption for both adsorbents. At this pH, H_3O^+ ions attract surface oxygenated adsorbent groups, which could lead to the formation of a bond between H_3O^+ and any doublet without malathion-sulfur. Below and above this pH value, adsorption is lower due to the hydrolysis of malathion at values higher than 8 and lower than 5 and the formation of ionic species with lower affinity for the adsorbent surface, i.e. precipitation contributes to ion removal.

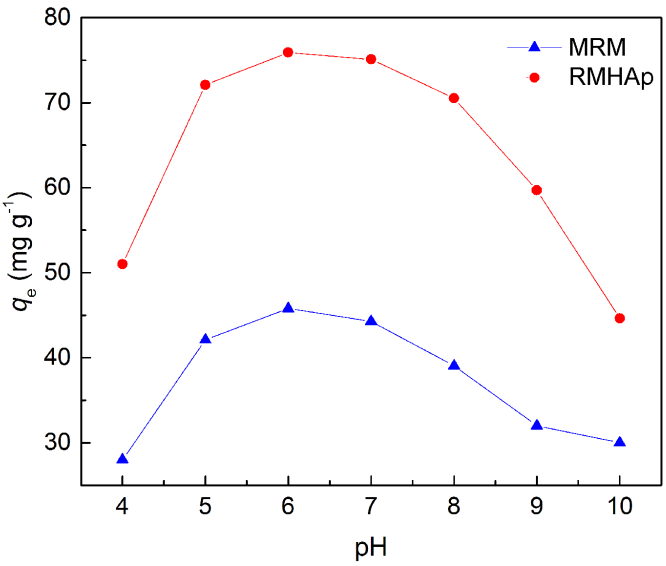

Figure 6 – Influence of the pH value of the initial solution on malathion removal
Рис. 6 – Влияние значения pH первичного раствора на удаление карбофоса.
Слика 6 – Утицај pH вредности почетног раствора на уклањање малатиона

Adsorption largely depends on the solution pH so the process itself is more favorable at medium pH values. Also in the natural environment (water) at pH values lower than 5 and higher than 8, malathion easily hydrolyzes to metabolites that are more toxic than malathion itself (Bouchard et al, 2003), which is another reason why sorption experiments are performed at pH 6.

Adsorption kinetics

The effect of time on malathion adsorption was monitored in the range of 10 to 180 minutes. The final equilibrium was established after 300 minutes but, since the difference in the removal of As (V) ions from 180 to 300 minutes ranged from 3 to 7% in order to speed up the process, we took 180 minutes as the final time.

In order to determine the kinetic model that accompanies adsorption in order to interpret the adsorption mechanism, we used pseudo-first, pseudo-second-order and second-order models (Table 3).

Table 8 shows the kinetic parameters for malathion absorption on MRM and RMHAp adsorbents.

Table 8 – The kinetic parameters for malathion adsorption on MRM and RMHAp adsorbents ($Ci_{[malathion]}$ = 20.32 mg L^{-1}, pH = 6; m/V = 100 mg L^{-1}, T = 25 °C)

Таблица 8 – Кинетические параметры адсорбции малатиона на адсорбентах MRM и RMHAp ($Ci_{[малатион]}$ = 20.32 mg L^{-1}, pH = 6; m/V = 100 mg L^{-1}, T = 25 °C)

Табела 8 – Кинетички параметри адсорпције малатиона на адсорбентима MRM и RMHAp ($Ci_{[malathion]}$ = 20.32 mg L^{-1}, pH = 6; m/V = 100 mg L^{-1}, T = 25 °C)

Adsorbent	Model parameters	Pseudo-first	Pseudo-second	Second-order
MRM	q_e	37.247	53.589	53.589
	k (k_1, k_2)	0.01589	0.00054	0.000093
	R^2	0.960	**0.992**	0.931
RMHAp	q_e	67.425	92.142	92.142
	k (k_1, k_2)	0.02041	0.00031	0.00025
	R^2	0.974	**0.994**	0.941

The results shown in Table 8, according to the regression coefficient (R^2) and the standard error for all model parameters, indicate that the kinetics for all adsorbents is best described using a pseudo-second order model.

The rate constants of diffusion kinetic models, intra-particle diffusion, Weber-Morris, Dunwald-Wagner and homogeneous solid diffusion models for malathion adsorption on MRM and RMHAp adsorbents under the same experimental conditions are presented in Table 9.

The complex nature of the kinetics of adsorption processes can be described by observing the adsorption of all ions adsorbed on the adsorbent as a single step, as described by a pseudo-second order equation, but can also be described by consecutive / competitive steps.

The Weber-Morris model reveals two linear steps that describe the adsorption process: fast kinetics in the first step and slower in the second. The first linear part describes the external mass transfer to the adsorbent surface, while the second part describes the process of material transfer into the porous structure of the adsorbent, and strictly depends on the size and shape of the pores as well as on the density of their network on MRM and RMHAp adsorbents. Intra-particle and film diffusions slow down the transport of adsorbates. In the final phase of the process, adsorption takes place slowly until saturation is achieved on the entire available surface of the adsorbent.

Table 9 – Parameters of diffusion kinetic models ($Ci_{[malathion]}$ = 20.32 mg L^{-1}, pH = 6; m/V = 100 mg L^{-1}, T = 25 °C)
Таблица 9 – Параметры диффузионных кинетических моделей ($Ci_{[малатион]}$ = 20.32 mg L^{-1}, pH = 6; m/V = 100 mg L^{-1}, T = 25 °C)
Табела 9 – Параметри дифузионих кинетичких модела ($Ci_{[malathion]}$ = 20.32 mg L^{-1}, pH = 6; m/V = 100 mg L^{-1}, T = 25 °C)

Adsorbent	Model	Model parameters	Values
MRM	Weber-Morris Step 1	k_{p1} (mg g^{-1} $min^{-0.5}$)	3.6188
	(Intra-particle diffusion)	*C* (mg g^{-1})	3.176
		R^2	0.995
	Weber-Morris Step 2	k_{p2} (mg g^{-1} $min^{-0.5}$)	0.304
	(equilibrium)	*C* (mg g^{-1})	40.247
		R^2	0.999
	Dunwald-Wagner model	*K*	0.00711
		R^2	0.953
	Homogenous Solid Diffusion Model (HSDM)	*Ds*	$9.34 \cdot 10^{-12}$
		R^2	0.950
RMHAp	Weber-Morris Step 1	k_{p1} (mg g^{-1} $min^{-0.5}$)	6.792
	(Intra-particle diffusion)	*C* (mg g^{-1})	2.286
		R^2	0.998
	Weber-Morris Step 2	k_{p2} (mg g^{-1} $min^{-0.5}$)	0.608
	(equilibrium)	*C* (mg g^{-1})	67.719
		R^2	0.999
	Dunwald-Wagner model	*K*	0.00698
		R^2	0.956
	Homogenous Solid Diffusion Model (HSDM)	*Ds*	$9.24 \cdot 10^{-14}$
		R^2	0.950

Adsorption activation energy

In relation to the results of the kinetic research performed at temperatures of 298, 308, and 318 K, it is possible to determine the activation energy using the Arrhenius equation (Table 10). The linear form of the Arrhenius equation (19) is:

$$\ln \mathrm{K}' = -\frac{E_a}{RT} + \ln A \qquad (19)$$

where *K'* is the reaction rate constant at a certain temperature, *Ea* shows the activation energy, *R* is the universal gas constant (8.314), T is the temperature in K and *A* is the Arenius factor (frequency for a given reaction).

Table 10 – Pseudo-second kinetic model parameters for malathion adsorption on MRM and RMHAp adsorbents ($Ci_{[malathion]}$ = 20.32 mg L^{-1}, pH = 6; m/V = 100 mg L^{-1})

Таблица 10 – Параметры псевдо-второго порядка кинетической модели адсорбции малатиона на адсорбентах MRM и RMHAp ($Ci_{[малатион]}$ = 20.32 mg L^{-1}, pH = 6; m/V = 100 mg L^{-1})

Табела 10 – Параметри псеудодругог кинетичког модела адсорпције малатиона на адсорбентима MRM и RMHAp ($Ci_{[malathion]}$ = 20.32 mg L^{-1}, pH = 6; m/V = 100 mg L^{-1})

Adsorbent	Temperature	q_e (mg g^{-1})	k_2 (g (mg min)$^{-1}$)	R^2
MRM	25 °C	53.594	0.000537	0.992
	35 °C	57.658	0.000636	0.992
	45 °C	62.271	0.000706	0.993
RMHAp	25 °C	92.142	0.000308	0.994
	35 °C	92.333	0.000351	0.995
	45 °C	94.224	0.000374	0.995

Physosorption or physical adsorption generally possesses energy up to 40 kJ mol^{-1}, while hemisorption requires higher energy and activation energy over 40 kJ mol^{-1} (Karanac et al, 2018). Based on the obtained results where Ea for MRM is 10.816 kJ mol^{-1} and for RMHAp 7.711 kJ mol^{-1}, we can conclude that the main mechanism of adsorption is physical adsorption.

Adsorption isotherms

The state of interactions / bonds on the surface of the adsorbate / adsorbent can be observed by fitting the experimental data with different adsorption isotherms. The normalized correlation coefficient and standard deviation were used to estimate the fit of the adsorption data.

The experimental data were compared with the Langmuir, Freundlich, Temkin, and Dubinin-Radushkevich isotherm models already discussed, the parameters of which are shown in Table 11. By analyzing the experimental data on the adsorption of malathion molecules on the tested adsorbents, the best fit for both adsorbents is given by the Freundlich isothermal model. The results of modeling malathion adsorption on the tested adsorbents are given in Table 11.

Table 11 – Parameters of the adsorption isotherms of malathion adsorption on MRM and RMHAp adsorbents
Таблица 11 – Параметры изотермы адсорбции малатиона на адсорбентах MRM и RMHAp.
Табела 11 – Параметризотерми адсорпције малатиона на адсорбентима MRM и RMHAp

Adsor-bent	Isothermal models and parameters		Temperature		
			25 °C	35 °C	45 °C
MRM	Langmuir isotherm	q_m (mg g^{-1})	46.462	48.135	49.789
		K_L (L mg^{-1})	1.918	1.968	2.027
		K_L (L mol^{-1})	633570	650164	669551
		R^2	0.992	0.994	0.995
	Freundlich isotherm	K_F (mg g^{-1}) (dm^3 mg^{-1})$^{1/n}$	28.469	29.252	30.066
		1/*n*	0.182	0.189	0.195
		R^2	**0.997**	**0.998**	**0.988**
	Temkin isotherm	A_T (dm^3 g^{-1})	443.06	376.95	329.44
		b_T	4.95	5.25	5.54
		R^2	0.980	0.980	0.978
	Dubinin-Radushkovich isotherm	q_m (mg g^{-1})	34.25	35.18	36.12
		K_{ad} (mol^2 kJ^{-2})	9.17	9.15	9.12
		Ea (kJ mol^{-1})	7.38	7.39	7.40
		R^2	0.802	0.796	0.791
RMHAp	Langmuir isotherm	q_m (mg g^{-1})	78.311	84.502	87.485
		K_L (L mg^{-1})	1.531	1.614	1.715
		K_L (L mol^{-1})	505829	533409	566567
		R^2	0.980	0.982	0.985
	Freundlich isotherm	K_F (mg g^{-1}) (dm^3 mg^{-1})$^{1/n}$	39.432	42.473	44.313
		1/*n*	0.275	0.279	0.289
		R^2	**0.998**	**0.996**	**0.987**
	Temkin isotherm	A_T (dm^3 g^{-1})	80.959	100.297	99.368
		b_T	10.03	10.17	11.05
		R^2	0.938	0.933	0.958
	Dubinin-Radushkovich isotherm	q_m (mg g^{-1})	47.82	49.48	51.05
		K_{ad} (mol^2 kJ^{-2})	8.84	8.81	8.78
		Ea (kJ mol^{-1})	7.52	7.53	7.55
		R^2	0.792	0.766	0.766

According to the Freundlich isotherm, the mechanism of ion adsorption on MRM and RMHAp can be described as heterogeneous adsorption, where the adsorbed ions / molecules have different enthalpies and adsorption activation energies. The value of n from the Freundlich isotherm is a measure of adsorption intensity or surface heterogeneity. Values of n near zero indicate a highly heterogeneous surface. Values of n <1 (Table 11) imply a hemisorption process, and

higher values indicate combined adsorption, e.g. physisorption and hemisorption with different process contributions at different system balancing steps. The values in Table 16 indicate that the adsorption was combined in all cases.

The calculation of the separation factor (R_L) according to equation (20) which is based on the parameter b of the Langmir isotherm indicates the feasibility of adsorption on a given adsorbent. It is calculated using the following equation:

$$R_L = \frac{1}{(1 + bC_0)} \tag{20}$$

where C_0 (mol L^{-1}) is the initial adsorbate concentration and b (L mol^{-1}) is the Langmir constant. The value of R_L indicates the feasibility of the adsorption process: irreversible (R_L = 0), favorable (0 <R_L <1), linear (R_L = 1), and unfavorable (R_L> 1). The R_L for adsorption of malathion ions on MRM ranges from 0.023 to 0.204 and for RMHAp from 0.027 to 0.243 indicating that the adsorption process is favorable.

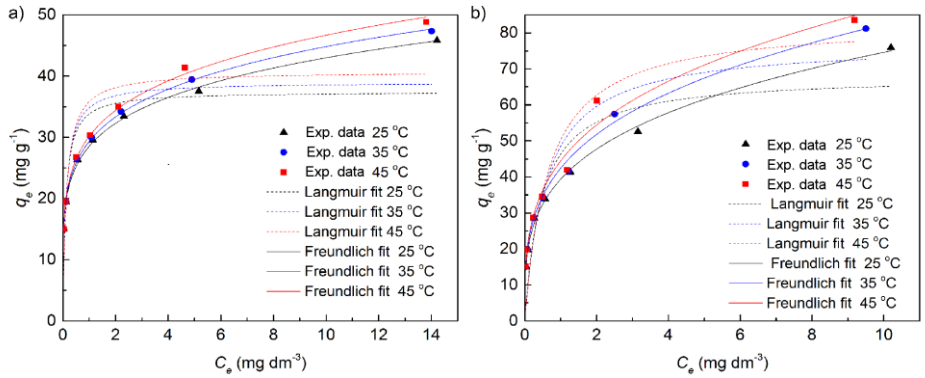

Figure 7 – Review of the results of the adsorption experiments with the best-fitting models of isotherms (solid line) for the removal of malathion on adsorbents MRM (a) and RMHAp (b)

Рис. 7 – Обзор результатов адсорбционных экспериментов с наиболее подходящими моделями изотерм (сплошная линия) для удаления малатиона на адсорбентах MRM (а) и RMHAp (б)

Слика 7 – Преглед резултата адсорпционих експеримената са најбоље уклопљеним моделима изотерми (пуна линија) за уклањање малатиона на адсорбентима MPM (а) и RMHAp (б)

Thermodynamic studies

Gibbs free energy (ΔG^0), enthalpy (ΔH^0) and entropy (ΔS^0) were calculated by Van't Hoff equation (21) and (22):

$$\Delta G^0 = -RT\, ln(b) \quad (21)$$

$$ln(b) = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{(RT)} \quad (22)$$

where T is the absolute temperature in *K, R* is the universal gas constant (8.314 mol^{-1} K^{-1}) and the adsorption constant b is calculated using the Langmir isotherm (Table 12). ΔH^0 and ΔS^0 were calculated from the slope and the sections in the diagram ln(*b*) - T^{-1}, assuming that the adsorption kinetics values are stationary. The calculated thermodynamic parameters are shown in Table 12.

Table 12 – Calculated Gibbs free adsorption energy, enthalpy and entropy for malathion adsorption on MRM, and RMHAp at 25, 35, and 45 °C
Таблица 12 – Расчет свободной адсорбционной энергии, по Гиббсу, энтальпия и энтропия адсорбции малатиона на MRM и RMHAp при 25, 35 и 45 °C
Табела 12 – Прорачун Гибсове слободне енергије, енталпије и ентропије адсорпције малатиона на MRM и RMHAp на 25, 35 и 45 °C

Adsorbent	ΔG° (kJ mol^{-1})			ΔH° (kJ mol^{-1})	ΔS° (J mol^{-1} K^{-1})	R^2
	25 °C	**35 °C**	**45 °C**			
MRM	-43.07	-44.58	-46.11	2.18	151.75	0.996
RMHAp	-42.51	-44.07	-45.66	4.47	157.56	0.997

Negative values of Gibbs free energy (*ΔG*°) and positive values of entropy (*ΔS*°) at all temperatures indicate that reactions in the adsorption process take place spontaneously. A decrease in the Gibbs free energy (*ΔG*°) with an increase in temperature also indicates that the spontaneity of the reaction increases.

Positive values of ΔS^0 indicate a tendency of greater disorder of the MRM and RMHAp surface systems and malathion solution. In Table 12, we can see that the Gibbs free energy values (*ΔG*°) for both adsorbents are approximate, and the positive entropy values (*ΔS*°) at all temperatures, while the positive enthalpy values (ΔH^0) for MRM and RMHAp are noticeable, which indicates the endothermic process. In general, the exchange of free energy in the case of physisorption is somewhere between -20 and 0 kJ mol^{-1}, for simultaneous hemisorption and physisorption between -20 and -80 kJ mol^{-1}, and hemisorption less than -80 kJ mol^{-1}. The obtained results indicate that in these cases, hemisorption and physisorption are present at the same time.

Optimization of adsorption conditions

The individual interaction and the impact of various variables in relation to different predictors were tested using the response surface methodology (RSM) as a mathematical function by commercial software design Expert 9. The mutual influence of the input variables was analyzed by analyzing the variances of ANOVA using the quadratic model of the equation shown in Table 13.

Table 13 – ANOVA variance analysis for a square response surface model for the removal of malathion from water using the RMHAp adsorbent
Таблица 13 – Дисперсионный анализ ANOVA квадратной модели поверхности отклика для удаления малатиона из воды с использованием адсорбента RMHAp
Табела 13 – Анализа варијанси ANOVA за квадратни модел једначине методе одзивних површина за уклањање малатиона из воде помоћу адсорбента RMHAp

Source	Sum of square	df	Mean Square	F Value	p-value Prob > F
Model	9102.20579	14	650.1575566	8.986135	0.0001 significant
A-dose adsorbent	4873.88213	1	4873.882133	67.36423	< 0.0001
B-t	991.173633	1	991.1736333	13.69948	0.0004
C-pH	3.8988	1	3.8988	0.053887	0.8198
D-T	18.8000333	1	18.80003333	0.259844	0.6182
AB	484	1	484	6.689593	0.0215
AC	0.9604	1	0.9604	0.013274	0.9099
AD	7.0225	1	7.0225	0.097061	0.7600
BC	0.297025	1	0.297025	0.004105	0.9498
BD	0.075625	1	0.075625	0.001045	0.9747
CD	0.783225	1	0.783225	0.010825	0.9186
A^2	756.17519	1	756.1751903	10.45145	0.0060
B^2	37.4530282	1	37.45302815	0.517656	0.4837
C^2	1399.36149	1	1399.361488	19.34124	0.0006
D^2	27.51492	1	27.51492005	0.380297	0.5473
Residual	1012.91668	14	72.35119167		
Lack of Fit	1012.90868	10	101.2908683	50645.43	< 0.0001 significant
Pure Error	0.008	4	0.002		
Cor Total	10115.1225	28			

A graph of the optimal conditions with respect to the input variables for removing malathion from water using RMHAp is shown in Figure 7.

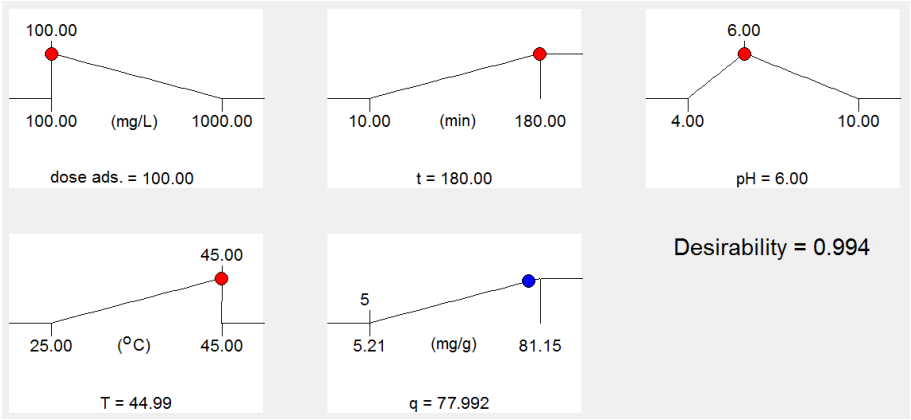

Figure 8 –- Optimization of the input parameters in relation to the maximum capacity of the adsorbent
Рис. 8 – Оптимизация входных параметров в зависимости от максимальной емкости адсорбента.
Слика 8 – Оптимизација улазних параметара у односу на максимални капацитет адсорбента

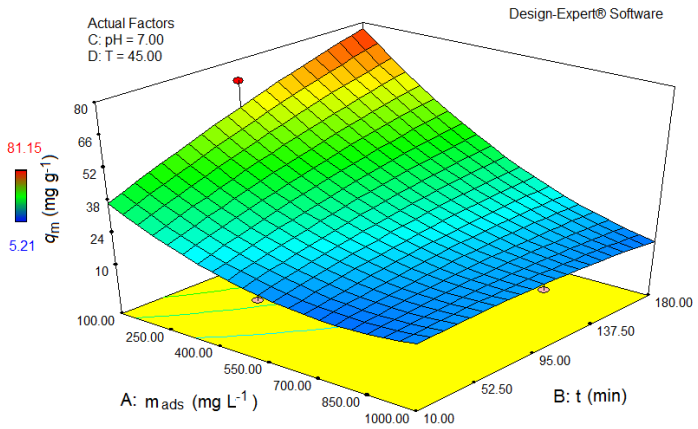

Figure 9 – 3D diagram of the mutual interactions of dependence of significant input variables (adsorbent dose and time)
Рис. 8 – Трехмерная диаграмма взаимодействий зависимостей значимых входных переменных (доза и время адсорбента)
Слика 8 – 3D дијаграм међусобних интеракција зависности значајних улазних променљивих (доза адсорбента и време)

Conclusion

MRM and RMHAP showed excellent malathion removal performance. The results of isothermal, kinetic, and thermodynamic studies suggested simultaneous physisorption and hemisorption between malathion molecules and the surface of MRM and RMHAP adsorbents during the adsorption process. The optimal parameters for the maximum malathion adsorption were: system pH value - 6, adsorbent dose - 100 mg L^{-1}, adsorption time - 180 minutes, and temperature - 45 °C. Adsorption was spontaneous and endothermic as described by thermodynamic parameters. The Bok-Behnken's design within the response surface method has been successfully used in the optimization of experimental adsorption conditions, the goal of optimization being to determine the optimal adsorption conditions with a smaller number of experiments. Optimization methods are maximally harmonized with the principles of environmental protection thus reducing: the number of experiments, the amount of consumed expensive and environmentally harmful chemicals, and the generation of waste. The errors and the predicted response values, derived from a mathematical model, showed acceptable results and confirmed the favorable effect of the studied factors on malathion adsorption using RMHAP. This paper investigates the sustainable use of biowaste for the treatment of water contaminated with organophosphorus pesticides, whereby the biowaste that burdens the banks of rivers is used to remove water pollutants, thus leading to a double benefit for the environment.

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ИЗМЕЛЬЧЕННЫЕ РАКОВИНЫ ПРЕСНОВОДНЫХ МОЛЛЮСКОВ В КАЧЕСТВЕ ДЕШЕВОГО АДСОРБЕНТА ДЛЯ УДАЛЕНИЯ МАЛАТИОНА ИЗ ВОДНОЙ СРЕДЫ: ИССЛЕДОВАНИЯ ИЗОТЕРМЫ, КИНЕТИКИ, ТЕРМОДИНАМИКИ И ОПТИМИЗАЦИЯ ЭКСПЕРИМЕНТАЛЬНЫХ УСЛОВИЙ МЕТОДОМ ПОВЕРХНОСТИ РЕАГИРОВАНИЯ

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РУБРИКА ГРНТИ: 61.00.00 ХИМИЧЕСКАЯ ТЕХНОЛОГИЯ. ХИМИЧЕСКАЯ ПРОМЫШЛЕННОСТЬ:
61.01.00 Общие вопросы химической технологии и химической промышленности.
61.01.91 Отходы химических производств и их переработка. Вторичное сырье. Ресурсосбережение.
61.01.94 Охрана окружающей среды

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье представлены результаты исследования возможности удаления фосфорорганического пестицида малатиона из водной среды с помощью нового адсорбента на основе биоотходов − раковин пресноводных моллюсков семейства Anodonta Sinadonta woodiane, материала, который в больших количествах накапливается в виде отходов на побережьях крупных рек.

Методы: Были испытаны два адсорбента − механически измельченные речные раковины (MRM) и гидроксиапатит из измельченных речных раковин, полученный механосинтезом (RMHAp). Полученные адсорбенты были исследованы (элементный анализ, сканирующая электронная микроскопия − SEM, энергодисперсионная рентгеновская спектроскопия − EDS, рентгеноструктурный анализ − HRD, инфракрасная спектроскопия с преобразованием Фурье (ИКФС, FTIR) и испытаны методом прерывания на удаление органофосфорного пестицида малатиона из водной среды. Оптимизация условий адсорбции проводилась методом поверхностей отклика − RSM, при этом исследовалось влияние переменных факторов (условий адсорбции), значений pH, доз адсорбента, времени контакта и температуры на адсорбционную способность адсорбента.

Результаты: Наилучшая адсорбция малатиона была достигнута при средних значениях pH от 6,0 до 7,0. Максимальная адсорбционная способность Ленгмюра по MRM и RMHAp при 25 ° C составляла 46 462 мг г$^{-1}$ и 78 311 мг г$^{-1}$. Результаты показали, что адсорбция малатиона на обоих адсорбентах соответствует кинетической модели псевдо-второго порядка и модели изотермы Фрейндлиха. Термодинамические параметры указывают на эндотермический, самопроизвольный характер, приемлимый в процессе адсорбции.

Выводы: В ходе исследования был получен дешевый биосовместимый адсорбент с отличными адсорбционными свойствами в отношении малатиона. Таким образом из отходов моллюсков извлекается двойная выгода: используются отходы, которыми завалены побережья различных водотоков, и удаляются загрязняющие воду вещества, оказывающие негативное воздействие на окружающую среду в целом.

Ключевые слова: удаление, адсорбент, кинетика, изотермы, оптимизация, пестициды, вода, пресноводные моллюски.

СПРАШЕНЕ ЉУШТУРЕ РЕЧНИХ ШКОЉКИ КАО ЈЕФТИНИ АДСОРБЕНТ ЗА УКЛАЊАЊЕ МАЛАТИОНА ИЗ ВОДЕ: ИСПИТИВАЊЕ ИЗОТЕРМИ, КИНЕТИКЕ, ТЕРМОДИНАМИКЕ И ОПТИМИЗАЦИЈА ЕКСПЕРИМЕНТАЛНИХ УСЛОВА МЕТОДОМ ОДЗИВНИХ ПОВРШИНА

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ОБЛАСТ: заштита животне средине, хемијско инжењерство
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У овом истраживању испитиване су могућности уклањања органофосфорног пестицида малатиона из воде помоћу нових адсорбената на бази биоотпада речних шкољки из породице Anodonta Sinadonta woodiane, материјала који се у великим количинама накупља као отпад на обалама великих река.

Методе: Синтетисана су два адсорбента: механички уситњена речна шкољка (MRM) и хидроксиапатит добијен механосинтезом из уситњених речних шкољки (RMHAp). Добијени адсорбенти су окарактерисани (елементарна анализа, скенирајућа електронска микроскопија – СЕМ, електродисперзивна спектроскопија – ЕДС, рендгенска дифракциона анализа – ХРД, Фуријева трансформација ИР зрака – ФТИР) и испитани у шаржном систему за уклањање органофосфорног пестицида малатиона из воде. Оптимизација услова адсорпције извршена је методом одзивних површина – РСМ, где је испитан утицај променљивих фактора (услова адсорпције), пХ вредности, дозе адсорбента, времена контакта и температуре на капацитет адсорбента.

Резултати: Најбоља адсорпција малатиона постигнута је при средњим пХ вредностима између 6,0 и 7,0. Максимални Лангмуиров капацитет адсорпције за MRM и RMHAp на 25°Ц износио је 46,462 мг $г^{-1}$ и 78,311 мг $г^{-1}$, редом. Резултати су показали да адсорпција малатиона на оба адсорбента следи псеудодруги кинетички модел и Фројндлихов изотермни модел. Термодинамички параметри указују на ендотермну, спонтану и изводљиву природу процеса адсорпције.

Закључак: У току истраживања добијен је јефтин биокомпатибилни адсорбент са одличним адсорпционим карактеристикама према малатиону. Коришћење отпада од шкољки врло је корисно: јер отпад који оптерећује обале различитих водотокова уклања загађиваче који оптерећују воду и изазивају негативне ефекте на животну средину уопште.

Кључне речи: уклањање, адсорбент, кинетика, изотерме, оптимизација, пестициди, вода, речне шкољке.

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UNCERTAINTY MODELING USING INTUITIONISTIC FUZZY NUMBERS

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Abstract:

Introduction/purpose: The paper discusses the selection of the most optimal supplier using the example of an unmanned aircraft when the decision maker has data of a qualitative nature. Problems that arise in practice in the selection of suppliers relate to the selection of adequate criteria as well as the way they are evaluated by the decision maker. One of the ways of assessing the criteria of a qualitative character is the usage of linguistic expressions, which gives decision makers the freedom to express their position and opinion through descriptive assessments. This method of assessment is not the most accurate and can introduce a certain amount of uncertainty for the decision maker.

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Methods: To solve the problem of uncertainty, the paper proposes a method of modeling data using intuitive fuzzy numbers. Intuitive fuzzy numbers are suitable for solving the problem of uncertainty in situations when it is necessary to review safety during the assessment. To rank suppliers, the ELECTRE method is used, which is adapted to intuitive fuzzy numbers (IF ELECTRE). The IF ELECTRE method was chosen because it clearly presents the potential of all suppliers, i.e. their advantages and disadvantages in relation to the required criteria.

Results: Using IF ELECTRE, the final results provide a shape of mutual preference or indifference between suppliers. The ranking clearly shows the potential of all suppliers, which in a future procurement can serve as a reference for decision making.

Conclusion: The contribution of this paper is reflected in the proposed model that can be used in practice to solve not only the problem of supplier selection, but also similar problems where the decision is made based on inaccurate data. Using these models seeks to reduce indecision and subjectivity in decision making.

Key words: fuzzy logic, fuzzy set, intuitionistic fuzzy set, IF ELECTRE method.

Introduction

Making decisions based on a large number of different data and information is a complex and demanding process. The decision-making process is further complicated when different views and opinions of experts are included in it or incomplete information about the decision-making problem is available. In order to overcome the problems of uncertainty, subjectivity and uncertainty, the theory of fuzzy logic is developed Lotfi Zadeh (Zadeh, 1965; Zadeh, 1975a; Zadeh, 1975b). The fuzzy logic theory has proven useful in complex systems where there is uncertainty about the input data needed to make certain decisions as well as in situations when a decision is made based on experience, intuition and subjective assessment of parameters by the decision maker. Initially, logic was applied mainly in engineering with the aim of solving various practical engineering problems, but so far it has evolved and found its application in areas such as artificial intelligence (Pokorni, 2021) and (Milošević et al, 2021).

The fuzzy approach to solve a problem provides simple and clear linguistic qualifications that describe the problem more relevantly. One of the methods most commonly used to model linguistic qualifications is various types of fuzzy numbers: type 1 (Dubois & Prade, 1978; Dubois & Prade, 1979) and (Zimmermann, 1996), type 2 (Mendel, 2003), Z-

numbers (Zadeh, 2011), rough numbers (Zheng et al, 2019), and intuitive fuzzy numbers (Atanassov, 1983; Atanassov, 1986). The shapes of the mentioned fuzzy numbers are most often triangular and trapezoidal, and one can also find the shapes of parabolas, logistic curves, etc. Another way to model inaccurate data is to use intervals. The interval is defined by decision makers where they allocate linguistic qualifications to a specific domain.

Problems that often occur in practice are problems of choosing the most favorable option. Whether it is a problem related to a process, activity or task, the decision maker makes judgments and decisions based on the available data. By the nature of the decision that is made, it contains a subjective attitude and opinion, regardless of whether the decision maker is biased or not in one of the offered options.

The motivation for the research stemmed from the need to minimize or eradicate the problems that occur when choosing the most optimal supplier. The most common problems that can be noticed when choosing a supplier are: wrongly chosen criteria and the presence of uncertainty or hesitation in evaluating the alternative by criteria. Wrongly chosen criteria can lead a decision maker in the wrong direction, which can result in a high ranking of a supplier who does not have the potential to meet all defined requirements. The presence of uncertainty and uncertainty in the assessment is very difficult to remove, but in some way a solution to this problem must be found.

A novelty in this paper is the definition of criteria for the procurement of an unmanned aircraft from the point of view of military logistic support, as well as the use of the IF ELECTRE method to model the uncertainty of data that occur during the procurement of armament.

Therefore, the aim of this paper is to propose adequate criteria to be considered for the procurement of unmanned aircraft, as well as for finding ways to model and minimize uncertainty in decision making, based on the example of choosing a supplier for unmanned aircraft.

To meet this goal, the research questions to be answered in this paper are: What criteria to choose as the most appropriate for the selection of suppliers of unmanned aircraft, how to model inaccurate and unclear data, how to reduce uncertainty and hesitation in decision making, as well as which method to use to rank suppliers without seeing a clear picture of the preferences of all suppliers?

The topic - the choice of suppliers - has been important lately. A large number of published papers deal with it using the fuzzy approach to model uncertainty, while the most common methods of multicriteria decision making are used for ranking. Hence the need to define

adequate criteria, with price not being the main and decisive factor, as in most other cases. So in this case, price does not play such an important role although it is in correlation with all the criteria. Nowadays, unmanned aerial vehicles are widely used for various military tasks, so it is necessary to look at the criteria from the point of view of logistical support.

In order to apply the mentioned methods of uncertainty modeling as well as to make a decision on the most favorable option, the paper analyzes the basics settings and algorithms of intuitive fuzzy numbers and fuzzy Electre methods. Based on an example in practice, the solution of the problem of choosing the most favorable supplier of unmanned aircraft is presented. The selection is realized by evaluating all options (alternatives) in linguistic terms based on defined criteria, which are of a qualitative nature. Linguistic expressions are modeled by intuitive fuzzy numbers whose domain is defined in the interval from 0 to 1.

Literature review

Bearing in mind that the aim of the paper is to model uncertainty using intuitive fuzzy numbers, as well as to use the ELECTRE method extended by intuitive fuzzy approach (IF ELECTRE) to rank suppliers, this section of the paper presents a review of the literature.

The creator of intuitive fuzzy numbers is the researcher Atanassov, who defined the fuzzy set and presented the mathematical apparatus. By analyzing the literature, one can find a large number of papers where intuitive fuzzy numbers were used. For modeling uncertainty using intuitive fuzzy numbers, the idea was found by analyzing a large number of papers where the results applied in practice justified the expectations of the authors. Choosing a dream home (Shureshjani, 2021) used the Best-Worst method extended with intuitive fuzzy numbers to make a decision with a large number of criteria, because the input data was unclear since decision makers were uncertain when evaluating alternatives. To purchase a smartphone (Arunodaya et al, 2020), he used an intuitive fuzzy approach combined with the MABAC method. Due to the impact of the COVID-19 pandemic on the agile choice of external suppliers of appliances (Goker, 2021), a model for outsourcing performance identification has been developed. By applying the intuitive fuzzy approach, the need for more agile providers was solved. The influence of the unclear numbers on the final results is presented using the example of risk assessment in construction projects (Šmidovnik & Grošelj, 2021). In addition to the above analyzes of the application of the

intuitive fuzzy approach, there are a number of papers from which the following solutions to the problem stand out: slow supply in the supply chain (Tavana et al, 2016), energy security assessment (Alipour et al, 2018), supplier selection (Kaur, 2014), selection of computer performance (Nirmala & Uthra, 2017), job selection for investing money (Zeng et al, 2014), selection of a nuclear power plant site (Das et al, 2017), and risk analysis of changes in industry (Kushwaha et al, 2020).

There are a number of methods and approaches for ranking alternatives. This paper uses a multi-criteria model of Electre (Elimination and Choice Translating Reality) developed by Bernard Roy and Bouyssou (Roy & Bouyssou, 1986) with their collaborators. In the literature review so far, the method of intuitive fuzzy ELECTRE (IF ELECTRE) has been used in a large number of studies that have solved certain problems related most often to comparing options and understanding the advantages of one option over another. Rouyendegh (2018) preferred intuitive fuzzy numbers over ordinary fuzzy numbers due to the complexity of problem solving as well as the indecision of decision makers in assigning values to the considered alternatives. Also, the original ELECTRE method cannot be efficiently managed due to the lack of precise data, so it is necessary to use the IF ELECTRE method. Rogulj and Kilić Pamuković (Rogulj et al, 2021) used IF ELECTRE to support decision makers in the process of managing the project of removing construction barriers for schools with children with disabilities. They chose this method because the results of applying the model clearly reflected the difference in the annihilated options. Also, it was used for the selection of suppliers of raw materials (Komsiyah et al, 2019), for the evaluation of the criteria of public transport projects (Jacek & Kruszyński, 2015), for the selection of the best project (Rouyendegh & Serpil, 2012), and for the selection of means of transport for logistic systems (Sokolova & Chernov, 2016).

The advantages of applying IF ELECTRE is the most efficient modeling of hesitation and uncertainty of the decision maker, i.e. its reliability in relation to other methods that are sensitive to the confidence of the decision maker in the assessment. By applying IF ELECTRE, a comparison of alternatives can be achieved even in situations where there is no clear preference for one of the alternatives. The results clearly present the potential of suppliers, and the method provides insight into how preferential some suppliers are over others and vice versa.

The limitation of the application of this method is a very complex mathematical apparatus, which makes it difficult to apply. For a larger number of alternatives and criteria, i.e. a large number of input data, it is

necessary to apply the method by programming in certain software packages. Other methods need to be used to determine the weights of the criteria because the IF ELECTRE method does not provide this possibility.

Intuitive fuzzy number analysis

The intuitive fuzzy number is suitable for modeling inaccurate data where the decision maker is unsure of the evaluation of a particular criterion, so that this uncertainty can be presented quantitatively.

The intuitive fuzzy set Âu $X = \{x\}$, (Atanassov, 1983: Atanassov, 1986) is represented by the following expression:

$$\tilde{A} = \left\{ x, \mu_{\tilde{A}}(x), \nu_{\tilde{A}}(x) \;\middle|\; x \in X \right\} \qquad (1)$$

where: $\mu_{\tilde{A}}(x) \to [0,1]$ and $\nu_{\tilde{A}}(x) \to [0,1]$, and where the following condition applies: $0 \le \mu_{\tilde{A}}(x) + \nu_{\tilde{A}}(x) \le 1 \quad \forall x \in X$.

The value $\mu_{\tilde{A}}(x), \nu_{\tilde{A}}(x) \in [0,1]$ denote the degree of affiliation and the degree of non-affiliation x for $\tilde{A}$.

For each intuitive fuzzy set X, valid: $\pi_{\tilde{A}}(x) = 1 - \mu_{\tilde{A}}(x) - \nu_{\tilde{A}}(x)$, where $\pi_{\tilde{A}}(x)$ is the intuitive index x in $\tilde{A}$, that is, the degree of indecision.

The intuitive index $\pi_{\tilde{A}}(x)$ indicates the degree of indecision of decision makers in making an assessment.

For $\pi_{\tilde{A}}(x)$ the following conditions also apply: $0 \le \pi_{\tilde{A}}(x) \le 1 \quad \forall x \in X$,

as well as $\pi_{\tilde{A}}(x) = 1 - \mu_{\tilde{A}}(x) - \left[1 - \mu_{\tilde{A}}(x)\right] = 0 \quad \forall x \in X$ non-affiliation x for $\tilde{A}$.

For intuitive fuzzy sets, it is important that they give the function of belonging and the function of non-belonging of a point at the same time x in the fuzzy set $\tilde{A}$.

The intuitive fuzzy set $\tilde{A}=\left\{x,\mu_{\tilde{A}}(x),\nu_{\tilde{A}}(x)\;\middle|\;x\in X\right\}$ which belongs to the set of real numbers is called the intuitive fuzzy number if:

- there are at least two points $x_0, x_1 \in X$ such that $\mu_{\tilde{A}}(x_0)=1 \; and \; \nu_{\tilde{A}}(x_1)=1,$

- affiliation function $\mu_{\tilde{A}}$ is fuzzy convex, and the function of non-affiliation ν_a is fuzzy concave,

- $\mu_{\tilde{A}}$ is semi-continuous from above, and ν_a is semi-continuous from below,

- $\sup A=\left\{x\in X,\; \nu_{\tilde{A}}(x_1)<1\right\}$ is located in a confined space.

To compare the two intuitive fuzzy numbers (Chen, 2019), the following rules apply:

$$A'=(\mu_a,\vartheta_a,\pi_a) \; and \; B'=(\mu_b,\vartheta_b,\pi_b)$$
$$1)\;\mu_a\geq\mu_b \; and \; \vartheta_a\leq\vartheta_b, \; then \; A\geq B;$$
$$2)\;\mu_a=\mu_b \; and \; \vartheta_a=\vartheta_b, \; then \; A=B;$$
$$S_a=\mu_a-\vartheta_a \; and \; H_a=\mu_a+\vartheta_a \qquad (2)$$
$$3)\;S_A>S_B, \; then \; A>B;$$
$$4)\;S_A=S_B \; and \; H_A=H_B, \; then \; A=B;$$
$$5)\;S_A=S_B \; and \; H_A\leq H_B, \; then \; A\leq B;$$

If $A' and B'$ are intuitive fuzzy numbers, then the following rules apply (Atanassov, 1983):

$$
\begin{aligned}
&A'+B'=\{(x,\mu_a(x)+\mu_b(x)-\mu_a(x)\times\mu_b(x),\upsilon_a(x)\times\upsilon_b(x)\mid x\in E\};\\
&A'-B'=\{(x,\min(\mu_a(x),\upsilon_b(x)),\max(\upsilon_a(x),\mu_b(x))\mid x\in E\};\\
&A'\otimes B'=\{(x,\mu_a(x)\times\mu_b(x),\upsilon_a(x)+\upsilon_b(x)-\upsilon_a(x)\times\upsilon_b(x)\mid x\in E\};\\
&A'\subset B',\forall x\in E,\ \mu_a(x)\le\mu_b(x),\upsilon_a(x)\ge\upsilon_b(x);\\
&A'=B',\forall x\in E,\ \mu_a(x)=\mu_b(x),\upsilon_a(x)=\upsilon_b(x);\\
&A':A^c=\{(x,\upsilon_a(x),\mu_a(x)\mid x\in E\};\\
&A'\cap B'=\{(x,\min(\mu_a(x),\mu_b(x)),\max(\upsilon_a(x),\upsilon_b(x))\mid x\in E\};\\
&A'\cup B'=\{(x,\max(\mu_a(x),\mu_b(x)),\min(\upsilon_a(x),\upsilon_b(x))\mid x\in E\};
\end{aligned}
\tag{3}
$$

If two intuitive fuzzy sets are observed $\tilde{A}=\left\{x,\mu_{\tilde{A}}(x),\nu_{\tilde{A}}(x),\pi_{\tilde{A}}(x)\,\middle|\,x\in X\right\}$ and $\tilde{B}=\left\{x,\mu_{\tilde{B}}(x),\nu_{\tilde{B}}(x),\pi_{\tilde{B}}(x)\,\middle|\,x\in X\right\}$, where is $\Delta\mu_i=\mu_{\tilde{A}}(x_i)-\mu_{\tilde{B}}(x_i)$, $\Delta\nu_i=\nu_{\tilde{A}}(x_i)-\nu_{\tilde{B}}(x_i)$ and $\Delta\pi_i=\pi_{\tilde{A}}(x_i)-\pi_{\tilde{B}}(x_i)$, the distance between two intuitive fuzzy sets can be calculated according to the following expressions given in Table 1.

Table 1 – An overview of how to determine the distance between two intuitive numbers
Таблица 1 – Обзор способов определения расстояние между двумя интуитивно понятными числами
Табела 1 – Преглед начина одређивања дистанце између два интуитивна броја

Author	Analytical expression
(Atanassov, 1986)	Hamming distance $d_h(A,B)=\frac{1}{2}\times\left[\sum_{i=1}^{n}(\lvert\mu_a(x_i)-\mu_b(x_i)\rvert+\lvert\upsilon_a(x_i)-\upsilon_b(x_i)\rvert+\lvert\pi_a(x_i)-\pi_b(x_i)\rvert)\right]$ za $X=\{x_1,..,x_n\}$
(Atanassov, 1986)	Normalization of Hamming distance $d_{n-H}(A,B)=\frac{1}{2n}\times\left[\sum_{i=1}^{n}(\lvert\mu_a(x_i)-\mu_b(x_i)\rvert+\lvert\upsilon_a(x_i)-\upsilon_b(x_i)\rvert+\lvert\pi_a(x_i)-\pi_b(x_i)\rvert)\right]$

Author	Analytical expression
(Atanassov, 1986)	Euclidean distance $d_e(A,B)=\sqrt{\frac{1}{2}\times\left[\sum_{i=1}^{n}(\mu_a(x_i)-\mu_b(x_i))^2+(\upsilon_a(x_i)-\upsilon_b(x_i))^2+(\pi_a(x_i)-\pi_b(x_i))^2\right]}$
(Atanassov, 1986)	Normalization of Euclidean distance $d_{n-e}(A,B)=\sqrt{\frac{1}{2n}\times\left[\sum_{i=1}^{n}(\mu_a(x_i)-\mu_b(x_i))^2+(\upsilon_a(x_i)-\upsilon_b(x_i))^2+(\pi_a(x_i)-\pi_b(x_i))^2\right]}$
(Park et al, 2013)	$D_p=1-\frac{1}{n}\sum_{i=1}^{n}\lvert\Delta\pi_i(x_i)\rvert$, where $\Delta\pi_i=\pi_{\tilde{A}}(x_i)-\pi_{\tilde{B}}(x_i)$
(Chen, 2016)	$D(\tilde{A},\tilde{B})=1-\frac{\lvert 2(\mu_A(x_i)-\mu_B(x_i))-(\nu_A(x_i)-\nu_B(x_i))\rvert}{3}\times\left(1-\frac{\pi_A(x_i)-\pi_B(x_i)}{2}\right)-\frac{\lvert 2(\nu_A(x_i)-\nu_B(x_i))-(\mu_A(x_i)-\mu_B(x_i))\rvert}{3}\times\left(1-\frac{\pi_B(x_i)-\pi_A(x_i)}{2}\right)$
(Luo & Ren, 2016)	$D(\tilde{A},\tilde{B})=1-\frac{1}{3n}\sum_{i=1}^{n}\left(\lvert\mu_A^2(x_i)-\mu_B^2(x_i)\rvert+\lvert\nu_A^2(x_i)-\nu_B^2(x_i)\rvert+\frac{\lvert m_A^2(x_i)-m_B^2(x_i)\rvert}{2}\right)$, $where: m_A(x_i)=\frac{\mu_A(x_i)+1-\nu_A(x_i)}{2}$, $that\ m_B(x_i)=\frac{\mu_B(x_i)+1-\nu_B(x_i)}{2}$.
(Zhang & Fu, 2006)	$D(\tilde{A},\tilde{B})=1-\frac{1}{2n}\sum_{i=1}^{n}\left(\lvert\delta_A(x_i)-\delta_B(x_i)\rvert+\lvert\alpha_A(x_i)-\alpha_B(x_i)\rvert\right)$, $where: \delta_A(x_i)=\mu_A(x_i)+\pi_A(x_i)\mu_A(x_i)$, $that\ \delta_B(x_i)=\mu_B(x_i)+\pi_B(x_i)\mu_B(x_i)$ $\alpha_A(x_i)=\nu_A(x_i)+\pi_A(x_i)\nu_A(x_i)$, $that\ \alpha_B(x_i)=\nu_B(x_i)+\pi_B(x_i)\nu_B(x_i)$

Analysis of the fuzzy Electre algorithm extended with an intuitive fuzzy number

There are a number of methods and approaches for ranking alternatives. In this paper, the multi-criteria model Electre (ÉLimination et Choix Traduisant la REalité) developed by Bernard Roy and his collaborators (Roy & Bouyssou, 1986), is used. The ELECTRE method

allows the decision maker to choose the best choice with maximum advantage and minimum conflicts in the function of different criteria, i.e. it clearly provides a picture of the value of each alternative. The method is based on pairwise comparisons of alternatives, which means that each alternative is compared with all other alternatives, based on which final recommendations can be made. The main advantage of this method is that it avoids compensation between the criteria and any normalization procedure, which distorts the original data. The method is based on pairwise comparisons of alternatives, which means: if the alternative "a" is better than the alternative "b" for most criteria and there is no criterion according to which the alternative "a" is strictly worse than the alternative "b", it can be said that the alternative "a" is better than the alternative "b".

This section presents the fuzzy Electre method extended with intuitive fuzzy numbers (Rouyendegh, 2018) and (Wu & Chen, 2011). The algorithm of the extended method is further presented through six steps.

Step 1. Formation of a decision matrix, where the decision maker evaluates the alternatives according to all criteria. Grades are expressed using intuitive fuzzy numbers $X_{ij} = \left(\mu_{ij}, v_{ij}\right)$.

$$X = \begin{bmatrix} (\mu_{11}, v_{11}) & (\mu_{12}, v_{12}) & \dots & (\mu_{1n}, v_{1n}) \\ (\mu_{11}, v_{11}) & (\mu_{22}, v_{22}) & \dots & (\mu_{2n}, v_{2n}) \\ (\mu_{31}, v_{31}) & (\mu_{32}, v_{32}) & \dots & (\mu_{3n}, v_{3n}) \\ (\mu_{m1}, v_{m1}) & (\mu_{m2}, v_{m2}) & \dots & (\mu_{mn}, v_{mn}) \end{bmatrix} \tag{4}$$

Step 2. Different methods can be used for determining the weight or importance of the criteria: usually the decision maker decides which method will determine the importance of each criterion, where the condition must be met so that: $\sum_{j=1}^{n} W_j = 1$, where $0 \le \omega_j \le 1$.

Step 3. Defining sets:

A) consent C_{kl}:

$$\begin{aligned} C_{kl} &= \left\{ j \middle| \mu_{kj} \ge \mu_{ij}, v_{kj} < v_{ij} \; i \; \pi_{kj} < \pi_{ij} \right\} \\ C'_{kl} &= \left\{ j \middle| \mu_{kj} \ge \mu_{ij}, v_{kj} < v_{ij} \; i \; \pi_{kj} \ge \pi_{ij} \right\} \\ C''_{kl} &= \left\{ j \middle| \mu_{kj} \ge \mu_{ij}, v_{kj} \ge v_{ij} \right\} \end{aligned} \tag{5}$$

B) discrepancy D_{kl} :

$$D_{kl} = \left\{ j \middle| \mu_{kj} < \mu_{ij}, \nu_{kj} \geq \nu_{ij}, \pi_{kj} \geq \pi_{ij} \right\}$$
$$D_{kl}^{'} = \left\{ j \middle| \mu_{kj} < \mu_{ij}, \nu_{kj} \geq \nu_{ij}, \pi_{kj} < \pi_{ij} \right\} \quad (6)$$
$$D_{kl}^{''} = \left\{ j \middle| \mu_{kj} < \mu_{ij}, \nu_{kj} < \nu_{ij} \right\}$$

Step 4. Formation of the consent matrix C_{pq} is the result of approvals and their weights; it is realized in accordance with the following:

$$g_{ki} = \omega_c \times \sum_{j \in C_{ki}} \omega_j + \omega_c^{'} \times \sum_{j \in C_{ki}^{'}} \omega_j + \omega_c^{''} \times \sum_{j \in C_{ki}^{*}} \omega_j \quad (7)$$

$$G = \begin{bmatrix} - & g_{12} & \ldots & g_{1m} \\ g_{21} & - & \ldots & g_{2m} \\ g_{(m-1)1} & \ldots. & - & g_{(m-1)m} \\ g_{m1} & g_{m2} & g_{m(m-1)} & - \end{bmatrix}$$

where $W' = \left\{ \omega_c, \omega_c^{'}, \omega_c^{''}, \omega_D, \omega_D^{'}, \omega_D^{''} \right\}$ is the relative importance of the criteria that decision makers can subjectively determine, so that the consent matrix can be written:

$$K = \begin{bmatrix} - & k_{12} & \ldots & k_{1m} \\ k_{21} & - & \ldots & k_{2m} \\ k_{(m-1)1} & \ldots. & - & k_{(m-1)m} \\ k_{m1} & k_{m2} & k_{m(m-1)} & - \end{bmatrix} \text{ where } k_{ki} = g^{*} - g_{ki} \quad (8)$$

g^{*} is the maximum consensus index.

Step 5. Formation of the matrix of discrepancies D_{pq} is the result of discrepancies and their weights, realized in accordance with the following

$$h_{ki} = \frac{\max_{j \in D_{ki}} \omega_D^{*} \times d\left(X_{kj}, X_{ij}\right)}{\max_{j \in J} \times d\left(X_{kj}, X_{ij}\right)}, \ \omega_D^{*} = \left\{ \omega_d, \omega_D^{'}, \omega_D^{''} \right\} \quad (9)$$

$$H = \begin{bmatrix} - & h_{12} & \ldots & h_{1m} \\ h_{21} & - & \ldots & h_{2m} \\ h_{(m-1)1} & \ldots. & - & h_{(m-1)m} \\ h_{m1} & h_{m2} & h_{m(m-1)} & - \end{bmatrix}$$

The discrepancy matrix is:

$$L=\begin{bmatrix} - & l_{12} & ... & l_{1m} \\ l_{21} & - & ... & l_{2m} \\ l_{(m-1)1} & .... & - & l_{(m-1)m} \\ l_{m1} & l_{m2} & l_{m(m-1)} & - \end{bmatrix}, \text{ where } l_{ki}=h^{*}-h_{ki}, \quad (10)$$

h^{*} is the maximum discrepancy index.

Step 6. Forming a dominance matrix R which represents the aggregation of the safety matrix and the uncertainty matrix, and it has the following form:

$$R=\begin{bmatrix} - & r_{12} & ... & r_{1m} \\ r_{21} & - & ... & r_{2m} \\ r_{(m-1)1} & .... & - & r_{(m-1)m} \\ r_{m1} & r_{m2} & r_{m(m-1)} & - \end{bmatrix}, \text{ where } r_{ki}=\frac{l_{ki}}{k_{ki}+l_{ki}} \quad (11)$$

Ranking of alternatives is realized in accordance with the following:

$$\overline{T}_{ki}=\frac{1}{m-1}\sum_{i=1,l\neq k}^{m} r_{ki},\ k=1,2,....,m, \quad (12)$$

where the best alternative is the one with the maximum value:

$$A=\max\left\{\overline{T}_{k}\right\} \quad (13)$$

Defining criteria and linguistic qualifications

When procuring funds, the decision maker is guided by the criteria that the asset should meet. The criteria are usually of technical and tactical nature. In most cases, the price criterion is taken into account when choosing a supplier. In this paper, the price criterion is not directly considered, bearing in mind that it indirectly influences the formation of other criteria that are interesting when it comes to the selection of suppliers of unmanned aircraft. It is known that in most papers, criteria of quantitative and qualitative nature are used. Quantitative criteria are easier to process, more understandable and acceptable to the decision maker, and as such cannot be changed. In this paper, the decision maker used criteria of a qualitative nature, which greatly complicates the decision-making process, given that qualitative evaluation criteria use linguistic variables.

Defining linguistic variables is one of the first steps in forming a fuzzy model, so it is necessary to first name the linguistic variable, determine the number, shape and area of affiliation. According to (Tanasijević et al, 2007), there are no explicit recommendations on how to name the appropriate linguistic variables.

Linguistic variables are represented through linguistic expressions (small, medium, large, etc.) and linguistic values (moderate, very, about, more or less, conjunctions "and" and "or", etc.). Linguistic variables are words from natural language. In order for linguistic variables to be used as qualitative values in fuzzy logic, it is necessary to translate them in the fuzzy number which has its own domain, i.e. membership function.

Defining the domains of each fuzzy number is the task of the decision maker, so that it corresponds to the physical boundaries of the variable. If the variable is not of physical origin then the domain is defined on a set of real numbers belonging to a predetermined domain such as a standard scale of measures. The next parameter that is very important in modeling is granulation.

Granulation represents the number of fuzzy sets that describe uncertainty, i.e. the number of linguistic statements by which the considered uncertainty can be described in a sufficiently good way. It is recommended that a maximum of seven linguistic terms be commonly used (Lootsma, 1993), as the human brain can focus attention on a maximum of seven items at a time. Increasingly, problem-solving software writing tools, such as Matlab, are being used to solve problems.

In this paper, for the purposes of evaluating the criteria, the following linguistic expressions are defined, presented on the interval: very low (VL) on the interval [0, 0.2]; low (L) at interval [0.2,0.4]; medium (eng. Medium - M) on the interval [0.4,0.6]; High (H - H) at interval [0.6, 0.8] and Very high (VH) at interval [0.8, 1]. The values on the interval are determined by the decision maker who gives evaluations based on his/her experience and expertise in the problem to be solved.

Application of the proposed algorithm

This section will show the application of the model for the selection of suppliers using an example of the procurement of an unmanned aircraft. To select the most suitable supplier, the fuzzy Electre method

described above and extended by an intuitive fuzzy number is used. An intuitive fuzzy number is used to model the uncertainty and inaccuracy in the evaluation of the criteria. The importance of the criteria and the relative importance of the criteria are determined subjectively by the decision makers based on their knowledge, experience and their own assessments.

Six suppliers (suppliers from A1 to A6) applied for the tender. The decision makers selected four most important criteria in their opinion, such as: business (K_1), customer relations (K_2), technology (K_3) and logistics (K_4). The "business" criterion is assessed on the basis of the reputation, financial stability and management capacity of the supplier. The criterion of "customer relations" is observed through previous experiences, business references and ease of communication with the supplier. The criterion of "technology" is observed through capacity, the possibility of developing new products, improving existing products and the ability to solve problems. The criterion "logistics" is observed through delivery time, maintenance support, flexibility in changing orders, and reliability of delivery.

The decision maker determined the importance of W=[w1,w2,w3,w4] for each criterion according to the following: business w_1=0.1, customer relations w_2=0.2, technology w_3=0.3, and logistics w_4=0.4,
as well as the relative importance of the criterion W '= [wc, wc', wc '', wd, wd ', wd''] in accordance with the following W' = [1,0.66,0.33,1,0.66,0.33].

Determining the evaluation of each criterion observed for each alternative (supplier) is based on knowledge, experience and assessment of decision makers. Grades are modeled by an intuitive fuzzy number $\tilde{A} = (\mu_i, \vartheta_i, \pi_i)$ and presented at intervals $0 \le \mu_i \le 1, 0 \le \vartheta_i \le 1, 0 \le \pi_i \le 1$.

Based on the collected data and research, the decision maker evaluated all alternatives according to all criteria and presented the results in Table 2.

Table 2 – Decision matrix modeled by intuitive fuzzy numbers
Таблица 2 – Матрица решений, смоделированная интуитивно понятными фаззи-числами
Табела 2 – Матрица одлучивања моделована интуитивним фази бројевима

K / A	K1			K2			K3			K4		
	μ_i	υ_i	π_i	μ_i	υ_i	π_i	μ_i	υ_i	π_i	μ_i	υ_i	π_i
A1	0.23	0.587	0.183	0.61	0.2	0.19	0.192	0.63	0.178	0.75	0.15	0.1
A2	0.33	0.554	0.116	0.25	0.61	0.14	0.63	0.192	0.178	0.0984	0.45	0.452
A3	0.3	0.197	0.503	0.45	0.36	0.19	0.259	0.56	0.181	0.31	0.66	0.03
A4	0.37	0.62	0.01	0.36	0.45	0.19	0.337	0.484	0.179	0.15	0.82	0.03
A5	0.38	0.2	0.42	0.29	0.39	0.32	0.32	0.35	0.33	0.5	0.25	0.25
A6	0.259	0.56	0.181	0.24	0.35	0.41	0.3	0.28	0.42	0.45	0.28	0.27

Following the steps applied in the fuzzy Electre method extended by an intuitive fuzzy number, the following results are obtained:

a) Results of the obtained consent conditions C_{kl} and the non-compliance conditions D_{kl} based on expressions (5) and (6)

b)

$$C_{ki} = \begin{bmatrix} - & 4 & - & - & 2,4 & 2,4 \\ 1 & - & 3 & 3 & 3 & 1,3 \\ - & - & - & 4 & 2 & - \\ - & - & 3 & - & - & - \\ - & 4 & - & - & - & 4 \\ 1 & 4 & - & - & - & - \end{bmatrix}, D_{ki} = \begin{bmatrix} - & 1,3 & - & - & - & 1 \\ 4 & - & - & - & 4 & 4 \\ 2 & 3 & - & 3 & - & - \\ 2 & 3 & 2,4 & - & - & - \\ 2,4 & 3 & 2 & - & - & - \\ 2,4 & 1,3 & - & - & 4 & - \end{bmatrix}$$

$$C_{ki}^{'} = \begin{bmatrix} - & 2 & 2,4 & 2,4 & - & - \\ 3 & - & - & - & - & - \\ 1,3 & 2 & - & 2 & - & 1 \\ 3 & 2 & - & - & - & - \\ 1,3 & 1,2 & 3,4 & 1,4 & - & 1 \\ 3 & - & 3,4 & 4 & - & - \end{bmatrix}, \quad D_{ki}^{'} = \begin{bmatrix} - & - & 1,3 & 3 & 1,3 & 3 \\ 2 & - & 2 & 2 & 1,2 & - \\ 4 & - & - & - & 3,4 & 3,4 \\ 4 & - & - & - & 1,4 & 4 \\ - & - & - & - & - & - \\ - & - & 1 & - & 1 & - \end{bmatrix}$$

$$C_{ki}^{"}=\begin{bmatrix} - & - & - & - & - & - \\ - & - & 1 & - & - & 2 \\ - & 4 & - & - & - & 2 \\ 1 & 1,4 & 1 & - & 2,3 & 1,2,3 \\ - & - & 1 & - & - & 2,3 \\ - & - & - & - & - & - \end{bmatrix}, \quad D_{ki}^{"}=\begin{bmatrix} - & - & - & 1 & - & - \\ - & - & 4 & 1,4 & - & - \\ - & 1 & - & 1 & 1 & - \\ - & - & - & - & - & - \\ - & - & - & 2,3 & - & - \\ - & 2 & 2 & 1,2,3 & 2,3 & - \end{bmatrix}$$

c) Results of the obtained own consent "G" based on expression (7):

$$G=\begin{bmatrix} - & 0.5332 & 0.3996 & 0.3996 & 0.6 & 0.6 \\ 0.2998 & - & 0.3333 & 0.3 & 0.3 & 0.4666 \\ 0.2664 & 0.2664 & - & 0.5332 & 0.2 & 0.1332 \\ 0.2331 & 0.2997 & 0.3333 & - & 0.1665 & 0.1998 \\ 0.2664 & 0.5998 & 0.4995 & 0.333 & - & 0.6331 \\ 0.2998 & 0.4 & 0.4662 & 0.2664 & 0 & - \end{bmatrix}$$

Results of the obtained own disagreement "H" based on expression (8):

$$H=\begin{bmatrix} - & 0.25587 & 0.49638 & 0.15055 & 0.66 & 0.63561 \\ 1 & - & 0.40553 & 0.33 & 1 & 1 \\ 0.66 & 0.99089 & - & 0.33 & 0.66 & 0.63802 \\ 0.66 & 0.73435 & 0.34632 & - & 0.66 & 0.66 \\ 0.82479 & 0.77196 & 0.27357 & 0.09495 & - & 0 \\ 1 & 0.97186 & 0.66 & 0.1583 & 0.66 & - \end{bmatrix}$$

d) Results of the obtained consent "K" based on expression (9):

$$K=\begin{bmatrix} - & 0.0999 & 0.2335 & 0.2335 & 0.0331 & 0.0331 \\ 0.3333 & - & 0.2998 & 0.3331 & 0.3331 & 0.1665 \\ 0.3667 & 0.3667 & - & 0.0999 & 0.4331 & 0.4999 \\ 0.4 & 0.3334 & 0.2998 & - & 0.4666 & 0.4333 \\ 0.3667 & 0.0333 & 0.1336 & 0.3001 & - & 0 \\ 0.3333 & 0.2331 & 0.1669 & 0.3667 & 0.6331 & - \end{bmatrix}$$

e) Results of the obtained discrepancy "L" based on expression (10):

$$L = \begin{bmatrix} – & 0.7441 & 0.5036 & 0.8495 & 0.34 & 0.3644 \\ 0 & – & 0.5945 & 0.67 & 0 & 0 \\ 0.34 & 0.0091 & – & 0.67 & 0.34 & 0.362 \\ 0.34 & 0.2657 & 0.6537 & – & 0.34 & 0.34 \\ 0.1752 & 0.228 & 0.7264 & 0.905 & – & 1 \\ 0 & 0.0281 & 0.34 & 0.8417 & 0.34 & – \end{bmatrix}$$

f) Results of the obtained domination "R" based on expression (11):

$$R = \begin{bmatrix} – & 0.8816 & 0.6832 & 0.7844 & 0.9113 & 0.9167 \\ 0 & – & 0.6648 & 0.6679 & 0 & 0 \\ 0.4811 & 0.0242 & – & 0.8702 & 0.4398 & 0.42 \\ 0.4595 & 0.4435 & 0.6856 & – & 0.4215 & 0.4397 \\ 0.3233 & 0.8726 & 0.8447 & 0.7510 & – & 1 \\ 0 & 0.1077 & 0.6707 & 0.6965 & 0.3494 & – \end{bmatrix}$$

g) Ranking of the obtained alternatives, based on expressions (12) and (13), Table 3:

Table 3 – Review of the obtained results
Таблица 3 – Обзор полученных результатов
Табела 3 – Преглед добијених резултата

	Value	Alternative	Rank
T_1	0.8355	A_1	1
T_2	0.2665	A_2	6
T_3	0.4471	A_3	4
T_4	0.4899	A_4	3
T_5	0.7583	A_5	2
T_6	0.3649	A_6	5

The final obtained results showed that the best ranked alternative is A_1, i.e. the worst ranked alternative is A_2. The alternative A_5 is, in the decision-maker's opinion, extremely close to the alternative A_1, which gives the possibility that the alternative A_5 could compete for the

purchase of an unmanned aircraft. The alternatives A_2 and A_6 do not meet the required criteria because their value is extremely low, so their further role in procurement is not to be considered. The alternatives A_3 and A_4 are also not shortlisted for the procurement of an unmanned aircraft, but in the next procurement they could apply if they work on improving the set criteria. The decision maker specifically focused on the criterion of "logistics" because the assumption is that all other criteria indirectly affect the criterion of "logistics", such as: price, warranty, delivery time, and technical documentation.

Conclusion

In this paper, one of the methods to model uncertainty using intuitive fuzzy numbers is presented. Bearing in mind that the evaluation criteria are of qualitative nature, it automatically implies that the evaluation is realized based on linguistic qualifications. The use of linguistic qualifications by nature generates a problem of subjectivity in assessment. In order to solve or reduce this problem, intuitive fuzzy numbers are proposed in this paper. The analysis of the literature cited in the paper showed that modeling by using intuitive fuzzy numbers reduces the inaccuracy, indecision and hesitation of the decision maker when evaluating the offered options.

The criteria based on which the alternatives were evaluated were proposed from the point of view of logistic support. In relation to a large number of random works, the criterion of price and costs is excluded, because when one looks at the proposed criteria, it could be seen that they indirectly affect them. In the paper, intuitive fuzzy numbers are presented at intervals from 0 to 1, with specific domains for each linguistic qualification.

To select the most favorable option, a multicriteria fuzzy ELECTRE model extended with an intuitive fuzzy number (IF ELECTRE) is proposed in the paper. The reason is that it gives the decision maker the opportunity to choose the best choice with maximum advantage and minimum conflicts as a function of different criteria, which clearly provides a picture of the value of each alternative, or preference between alternatives.

The models and algorithms applied in selecting the most favorable option (supplier) for an unmanned aircraft clearly show the differences between suppliers, which can help the decision maker in future procurement. The options A_2 and A_6 showed a low value in terms of

references and previous experience, which is guidance to the decision maker not to consider them in future procurement.

It can be concluded that such a model of combined models and algorithms can be used in selecting the most favorable supplier because it clearly shows the differences between all options, as well as their values. Indecision and hesitation in assessment are minimized by applying an intuitive approach.

Depending on the problem to be solved, there is a need to generate hybrid models to make the best use of them in practice. In further research, it is necessary to use other methods to determine the weight of the criteria, such as the Best-Worst method, AHP and other methods extended with intuitive fuzzy numbers. It is also necessary to use other methods of multicriteria decision making extended by intuitive fuzzy numbers to compare alternatives. It is necessary to compare the obtained results and suggest the alternatives that are best ranked, and to suggest the used models for solving similar problems.

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МОДЕЛИРОВАНИЕ НЕОПРЕДЕЛЕННОСТИ С ПОМОЩЬЮ ИНТУИЦИОНИСТСКИХ НЕЧЕТКИХ ЧИСЕЛ

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РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА:
27.47.00 Математическая кибернетика;
27.47.19 Исследование операций,
80.00.00 ПРОЧИЕ ОТРАСЛИ ЭКОНОМИКИ:
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Логистика
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В статье обсуждается выбор наиболее оптимального поставщика на примере беспилотного летательного аппарата, в тех случаях, когда ответственное лицо, принимающее решение, владеет данными качественного характера. Проблемы, возникающие на практике при выборе поставщиков, связаны с выбором соответствующих критериев, а также с тем, как они оцениваются лицом, принимающим решения. Одним из способов оценки критериев качественного характера является использование лингвистических средств, предоставляющих лицам, принимающим решения, свободу выражать свою позицию и мнение методом описательной оценки. Так как данный метод оценки не самый точный, он может внести неопределенность при принятии решения.

Методы: Для решения проблемы неопределенности в данной статье предлагается метод моделирования данных с использованием интуитивно понятных фаззи-чисел. Интуитивно понятные фаззи-числа приемлемы для решения проблемы неопределенности в ситуациях, когда необходимо проанализировать безопасность оценивания. Для ранжирования поставщиков используется метод ELECTRE, адаптированный к интуитивно понятным фаззи-числам (IF ELECTRE). Метод IF ELECTRE был выбран благодаря его четкости в представлении потенциала всех поставщиков, то есть их преимуществ и недостатков по отношению к требуемым критериям.

Результаты: Используя IF ELECTRE, конечные результаты демонстрируют взаимное предпочтение или безразличие между поставщиками. Ранжирование четко выявляет потенциал всех поставщиков, который в будущих закупках может послужить ориентиром при принятии решений.

Выводы: Научный вклад данной статьи заключается в предложенной модели, которая может применяться на практике для решения не только проблемы выбора поставщика, но и аналогичных задач, решение которых принимается на

основании неточных данных. Применение представленных моделей способствует снижению нерешительности и субъективности при принятии решений.

Ключевые слова: нечеткая логика, фаззи-числа, интуитивно понятные фаззи-числа, IF ELEKTRE.

МОДЕЛОВАЊЕ НЕИЗВЕСНОСТИ ПРИМЕНОМ ИНТУИТИВНИХ ФАЗИ БРОЈЕВА

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ОБЛАСТ: индустријско инжењерство, инжењерски менаџмент
ВРСТА ЧЛАНКА: оргинални научни рад

Сажетак:

Увод/циљ: У раду је разматран избор најповољнијег добављача на примеру беспосадне летелице, у случају када доносилац одлуке располаже подацима квалитативног карактера. Проблеми који се јављају у пракси при избору добављача односе се на избор адекватних критеријума, као и начин на који их доносилац одлуке оцењује. Један од начина оцењивања критеријума квалитативног карактера јесте коришћење лингвистичких израза, који доносиоцу одлуке дају слободу да свој став и мишљење искаже помоћу описних оцена. Овакав начин оцењивања није најпрецизнији, што доносиоцу одлуке може изазвати одређену дозу неизвесности. .

Методе: За решавање проблема неизвесности, у раду је предложена метода моделовања података применом интуитивних фази бројева. Они су погодни за решавање проблема неизвесности у ситуацијама када је потребно да се преиспита сигурност приликом оцењивања. За рангирање добављача у раду се користи метода ELEKTRE која је прилагођена интуитивним фази бројевима (ИФ ELEKTRE). Метода ИФС ELEKTRE одабрана је због тога што јасно презентује потенцијал свих добављача, односно њихове предности и недостатке у односу на захтеване критеријуме.

Резултати: Коришћењем ИФ ELEKTRE коначни резултати пружају слику о међусобној преферентности, односно индиферентности између добављача. Рангирањем су јасно приказани потенцијали свих добављача, што у некој наредној набавци може послужити као референца за доношење одлуке.

Закључак: Допринос овог рада огледа се у предложеном моделу који у пракси може послужити за решавање проблема избора добављача, али и сличних проблема када се одлука доноси на основу непрецизних података. Коришћењем наведених модела смањује се неодлучност и субјективност при доношењу одлуке.

Кључне речи: фази логика, фази број, интуитивни фази број, ИФ ELEKTRE.

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ПРЕГЛЕДНИ РАДОВИ

ОБЗОРНЫЕ СТАТЬИ

REVIEW PAPERS

CORRECTIONS TO PROPAGATORS OF QUANTUM ELECTRODYNAMICS

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ARTICLE TYPE: Review paper

Abstract:

Introduction/purpose: The problem of quantum corrections to propagators in Quantum Electrodynamics (QED) is discussed.

Methods: The Dyson–Schwinger equation is employed for correcting propagators in QED.

Results: The observable quantities in QED are finite.

Conclusions: QED divergencies can be avoided by redefining physical quantities in a suitable manner.

Key words: Quantum Electrodynamics, Quantum Field Theory, Renormalization Group

QED loops

Corrected photon propagator

In (Fabiano, 2021) we have computed the correction to the photon line at one-loop level in QED. Remembering that the bare photon propagator is given by the expression

$$iD_{\mu\nu}(q) = -i\frac{g_{\mu\nu}}{q^2 + i\varepsilon} \tag{1}$$

obtained, roughly speaking, by inverting the term F^2 in the Lagrangian (5) of (Fabiano, 2021). In Minkowskian metric the vacuum polarisation is given

by

$$\Pi_{\mu\nu}(q) = (q_\mu q_\nu - g_{\mu\nu} q^2)\pi(q^2) \; . \tag{2}$$

The *physical* or *renormalised* photon propagator is obtained by considering all possible corrections to the photon line, as illustrated in eq. (3).

$iD^P_{\mu\nu} =$  (3)

As we can see, the physical photon propagator $iD^P_{\mu\nu}$ is obtained by repeated insertions of vacuum polarisation diagrams at one-loop level, in the following manner:

$$\begin{aligned} iD^P_{\mu\nu}(q) = iD_{\mu\nu}(q) + iD_{\mu\lambda}(q) i\Pi_{\lambda\rho}(q) iD_{\rho\nu}(q) + \\ iD_{\mu\lambda}(q) i\Pi_{\lambda\rho}(q) iD_{\rho\kappa}(q) i\Pi_{\kappa\sigma}(q) iD_{\sigma\nu}(q) + \ldots \end{aligned} \tag{4}$$

Recalling the geometric series for which this expression holds true

$$\sum_{n=1}^{+\infty} (-x)^n = \frac{1}{1+x} \; , \tag{5}$$

one could immediately recognise the same pattern in eq. (4) and rewrite it as (Dyson, 1949), (Schwinger, 1951)

$$\begin{aligned} iD^P_{\mu\nu}(q) = \frac{-i}{q^2} g_{\mu\nu} \left\{ 1 - \pi(q^2) + [\pi(q^2)]^2 + \ldots \right\} + \mathcal{O}(q_\mu q_\nu) = \\ \frac{-i}{q^2} g_{\mu\nu} \frac{1}{1+\pi(q^2)} + \mathcal{O}(q_\mu q_\nu) \; . \end{aligned} \tag{6}$$

Corrected electron propagator

Proceeding in a manner completely analogous to previous section we could calculate the physical electron propagator. The bare electron propa-

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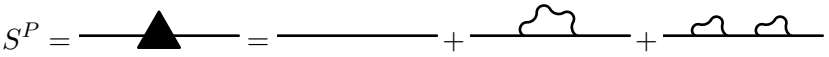
gator is given by

$$S(p) = i\frac{1}{\not{p} - m + i\varepsilon} = i\frac{\not{p} + m}{p^2 - m^2 + i\varepsilon} \ , \tag{7}$$

while the physical propagator $S^P(p)$ is obtained by repeated insertions of $\Sigma(p)$ calculated in (Fabiano, 2021), formula (27):



(8)

The expression for S^P is pictorially represented in eq. (8), this translates to:

$$S^P(p) = S(p) + S(p)\Sigma(p)S(p) + S(p)\Sigma(p)S(p)\Sigma(p)S(p) + \ldots \tag{9}$$

and using eq. (5) we end with the expression

$$S^P(p) = i\frac{1}{\not{p} - m - \Sigma(p) + i\varepsilon} \ . \tag{10}$$

Counterterms

Up to now, we have computed all possible fundamental divergencies in QED. Those are necessary to build the necessary *counterterms* in order to renormalise QED. Those counterterms are suitably constructed terms in the Lagrangian in order to cancel out divergencies and make results finite. To recap, we started with this classical Lagrangian in D dimensions

$$\mathcal{L}_{cl} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + i\overline{\psi}\not{\partial}\psi + e\mu^{(4-D)/2}\overline{\psi}\not{A}\psi - m\overline{\psi}\psi \ , \tag{11}$$

and we add a counterterm Lagrangian with the *same form* of the present Lagrangian of (11)

$$\mathcal{L}_{ct} = -\frac{1}{4}K_3F^{\mu\nu}F_{\mu\nu} + iK_2\overline{\psi}\not{\partial}\psi + e\mu^{(4-D)/2}K_1\overline{\psi}\not{A}\psi - mK_m\overline{\psi}\psi \ . \tag{12}$$

The obtained renormalised Lagrangian

$$\mathcal{L}_{ren} = \mathcal{L}_{cl} + \mathcal{L}_{ct} \tag{13}$$

could be expressed in terms of the bare quantities defined in the following way:

$$\psi_0 = \sqrt{1+K_2}\psi = Z_2^{1/2}\psi \tag{14}$$

$$A_0^\mu = \sqrt{1+K_3}A^\mu = Z_3^{1/2}A^\mu \tag{15}$$

$$e_0 = e\mu^{(4-D)/2}\frac{1+K_1}{(1+K_2)\sqrt{1+K_3}} = \frac{Z_1}{Z_2 Z_3^{1/2}}e\mu^{(4-D)/2} \tag{16}$$

$$m_0 = m\frac{1+K_m}{1+K_2} = \frac{Z_m}{Z_2}m \tag{17}$$

where we have introduced Dyson's Z notation (Dyson, 1952), and bare quantities, which do not depend on the scale μ, are denoted by a 0 subscript. Often, eq. (14) is called *wave function renormalisation*. The renormalised Lagrangian is

$$\mathcal{L}_{ren} = -\frac{1}{4}F_0^{\mu\nu}F_{0\mu\nu} + i\overline{\psi}_0\partial\!\!\!/\psi_0 + e_0\overline{\psi}_0 A\!\!\!/_0\psi_0 - m_0\overline{\psi}_0\psi_0 \ , \tag{18}$$

or in Dyson's notation

$$\mathcal{L}_{ren} = -\frac{Z_3}{4}F^{\mu\nu}F_{\mu\nu} + iZ_2\overline{\psi}\partial\!\!\!/\psi + eZ_1\overline{\psi}A\!\!\!/\psi - mZ_m\overline{\psi}\psi \ . \tag{19}$$

The covariant derivative in $\mathcal{L}_{ren}$ transforms as

$$\mathcal{D}_{ren}^\mu = \partial^\mu - ie\frac{Z_1}{Z_2}A^\mu \tag{20}$$

and, in order not to spoil gauge invariance of the Lagrangian it needs to be $Z_1 = Z_2$. It is possible to show that this is actually the case to all orders of perturbation theory.

The counterterms can be read off the one–loop calculations encountered in (Fabiano, 2021). Starting with fermion line correction, from eq. (37) of (Fabiano, 2021) we extract the term

$$\Sigma(p) = -i\frac{e^2}{16\pi^2}(p\!\!\!/ + 4m)\frac{1}{\varepsilon} + \text{finite terms} \tag{21}$$

and comparing to the inverse of the bare electron propagator, eq. (7)

$$S^{-1}(p) = -i(p\!\!\!/ - m + i\varepsilon) \tag{22}$$

one could infer that the term in $\not{p}$ is related to Z_2, while the term proportional to m is related to Z_m. Therefore

$$K_2 = -\frac{e^2}{16\pi^2}\left[\frac{1}{\varepsilon} + F_2\left(\varepsilon, \frac{m}{\mu}\right)\right] \tag{23}$$

and

$$K_m = -\frac{e^2}{4\pi^2}\left[\frac{1}{\varepsilon} + F_m\left(\varepsilon, \frac{m}{\mu}\right)\right] , \tag{24}$$

where functions F_2 and F_m are arbitrary finite parts depending upon ε and m/μ, and are analytical as $\varepsilon \to 0$. It means that the counterterms contain just the part proportional to $\frac{1}{\varepsilon}$ necessary to cancel the overall divergencies.

The second correction we tackle is the one for the photon line encountered in (Fabiano, 2021). From eq. (22) of (Fabiano, 2021) we have

$$\Pi_{\mu\nu}(q) = (q_\mu q_\nu - \delta_{\mu\nu}q^2)\left[\frac{e^2}{12\pi^2}\frac{1}{\varepsilon} + \text{finite terms}\right] , \tag{25}$$

and using the relation of eq. (4) we have for the one–loop propagator

$$D_{\mu\nu}(p) = \frac{\delta_{\mu\nu}}{p^2} + \frac{\delta_{\mu\nu}}{p^2}\Pi\frac{\delta_{\mu\nu}}{p^2} + \cdots = \frac{\delta_{\mu\nu}}{p^2}\left[1 - \frac{e^2}{12\pi^2}\frac{1}{\varepsilon}\right] + \frac{p_\mu p_\nu}{p^4}\frac{e^2}{12\pi^2}\frac{1}{\varepsilon} + \cdots \tag{26}$$

so that

$$K_3 = -\frac{e^2}{12\pi^2}\left[\frac{1}{\varepsilon} + F_3\right] \tag{27}$$

where F_3 is an arbitrary dimensionless finite function.

Last comes the vertex correction, from (Fabiano, 2021) eq. (50) we have

$$\Gamma_\rho(p,q) = -ie\mu^\varepsilon\gamma_\rho\left[\frac{e^2}{16\pi^2}\frac{1}{\varepsilon} + \text{finite terms}\right] \tag{28}$$

that gives

$$K_1 = -\frac{e^2}{12\pi^2}\left[\frac{1}{\varepsilon} + F_1\right] \tag{29}$$

where, once more, F_1 is a finite function. In terms of the Z notation, we summarise our results as

$$Z_1 = 1 - \frac{e^2}{16\pi^2}\left[\frac{1}{\varepsilon} + F_1\right] + \mathcal{O}(e^4) \tag{30}$$

$$Z_2 = 1 - \frac{e^2}{16\pi^2}\left[\frac{1}{\varepsilon} + F_2\right] + \cdots \tag{31}$$

$$Z_3 = 1 - \frac{e^2}{12\pi^2}\left[\frac{1}{\varepsilon} + F_3\right] + \cdots \tag{32}$$

$$Z_m = 1 - \frac{e^2}{4\pi^2}\left[\frac{1}{\varepsilon} + F_m\right] + \cdots \tag{33}$$

We remark once more that $Z_1 = Z_2$ is satisfied to this order in perturbation theory. So using the relation of eq. (16) and remembering that $\varepsilon = (4 - D)/2$, for $D \to 4$ we have

$$e_0 = e\mu^{2\varepsilon}\left[1 + \frac{e^2}{24\pi^2}\frac{1}{\varepsilon} + \text{finite terms} + \mathcal{O}(e^3)\right] . \tag{34}$$

If we ignore the finite part of the counterterms by adopting a mass independent prescription, also known as the *minimal subtraction scheme*, or MS scheme ('t Hooft, 1973), (Weinberg, 1973), for which the finite part is zero, we can compute the so–called *beta function* due to Gell–Mann and Low (Gell–Mann and Low, 1954) defined in the following way:

$$\beta(e) = \lim_{\varepsilon \to 0} \mu \frac{\partial e}{\partial \mu} , \tag{35}$$

which is an analytic function in ε. Compute the beta function from eq. (34) by differentiating with respect to μ, remembering that μ_0 is constant taking the prescribed limit $\varepsilon \to 0$, and obtain

$$\beta(e) = \mu \frac{\partial e}{\partial \mu} = \frac{e^3}{12\pi^2} \tag{36}$$

which is actually a differential equation for electric charge e as a function of a mass scale μ:

$$12\pi^2 \int_{e_0}^{e} \mathrm{d}e \, \frac{1}{e^3} = \int_{\mu_0}^{\mu} \mathrm{d}\mu \, \frac{1}{\mu} , \tag{37}$$

where μ_0 is an arbitrary scale. The explicit solution to this equation is

$$\frac{1}{e^2(\mu)} - \frac{1}{e^2(\mu_0)} = -\frac{1}{6\pi^2} \log\left(\frac{\mu}{\mu_0}\right) \tag{38}$$

which can be written in an explicit form for $e^2(\mu)$:

$$e^2(\mu) = \frac{e^2(\mu_0)}{1 - \frac{e^2(\mu_0)}{6\pi^2} \log\left(\frac{\mu}{\mu_0}\right)} . \tag{39}$$

A few comments on eq. (39). It has a singularity at the point

$$\mu = \mu_0 \exp[6\pi^2 e^{-2}(\mu_0)] \,, \tag{40}$$

better known as the *Landau pole* (Landau et al, 1954), (Landau and Pomeranchuk, 1955). A careful evaluation in QED shows that the Landau pole is of order of 10^{284} eV, a huge scale much larger than anything envisaged so far – for instance the Large Hadron Collider (LHC) works at about 10^{13} eV, while the *Planck scale*, that is a scale at which quantum gravity effects should become relevant, $\sqrt{\hbar c^5/G}$, is at "only" 10^{28} eV.

As the energy scale increases, or conversely, the distance decreases, the electron charge increases.

Running coupling constant

The formalism of the beta function and the existence of a so–called *running coupling constant*[1] is not a peculiarity of QED but it is standard behaviour in any quantum field theory. We have seen that in the minimal subtraction scheme the counterterms in the Lagrangian have no finite parts, therefore can be expanded in a Laurent series in ε containing only divergent parts. Call the generic renormalised coupling constant g and its bare version g_0, then the above statement could be written as (hereafter, $\varepsilon = 4 - D$)

$$g_0 = \mu^\varepsilon \left[g + \sum_{k=1}^{+\infty} \frac{g_k(g)}{\varepsilon^k} \right] \,, \tag{41}$$

where g_k are regular functions in g. Analogous expansions exist for bare mass m_0 and bare fields ψ_0, A_0^μ.

Now, a crucial observation is that all bare quantities are independent of the scale by definition. As the bare coupling constant is not dependent upon μ, $dg_0/d\mu = 0$. Applying the derivative to eq. (41), one obtains

$$\varepsilon g + \left(g_1 + \mu \frac{\partial g}{\partial \mu} \right) + \sum_{k=1}^{+\infty} \frac{1}{\varepsilon^k} \left[\frac{dg_k}{dg} \mu \frac{\partial g}{\partial \mu} + g_{k+1} \right] = 0 \,. \tag{42}$$

We have already discussed that $\mu \partial g/\partial \mu$ is an analytical function in ε, so we can write it as follows:

$$\mu \frac{\partial g}{\partial \mu} = \sum_{n=0}^{+\infty} d_n \varepsilon^n \,, \tag{43}$$

[1] An oxymoron!

and insert this form into eq. (42).

We obtain the equation for coefficients d of the beta function:

$$\varepsilon(g+d_1)+\left(g_1+d_0+d_1\frac{dg_1}{dg}\right)+\sum_{k=1}^{+\infty}\frac{1}{\varepsilon^k}\left[g_{k+1}+d_0\frac{dg_k}{dg}+d_1\frac{dg_{k+1}}{dg}\right]=0\ , \tag{44}$$

and observe that only the first two d terms survive, d_0 and d_1, so that eq. (43) is only linear in ε. We group different powers of ε, and each one of them has to vanish separately, so we have

$$\begin{aligned}(g+d_1)&=0\\ g_1+d_1\frac{dg_1}{dg}&=-d_0\\ \left(1+d_1\frac{d}{dg}\right)g_{k+1}&=-d_0\frac{dg_k}{dg}\ .\end{aligned} \tag{45}$$

Solving eqs. (45) and plugging it back in eq. (43) we end up with

$$\mu\frac{\partial g}{\partial\mu}=-g_1+g\frac{dg_1}{dg}-g\varepsilon\ , \tag{46}$$

and taking the limit $\varepsilon\to 0$:

$$\beta(g)=-g_1+g\frac{dg_1}{dg}\ . \tag{47}$$

We also found the recurrence relation for the coefficients of the counterterms:

$$\left(1-g\frac{d}{dg}\right)\left[g_{k+1}(g)-g_1(g)\right]=\frac{d}{dg}g_k(g)\ . \tag{48}$$

This recursion relation is very important because it shows that the coefficients of higher order poles can, at least in principle, be computed from just the knowledge of the simple pole term. So, in the minimal subtraction scheme we have seen that the beta function depends only on the coupling constant g, and the latter depends only on the scale μ; therefore, we can write

$$\mu\frac{dg(\mu)}{d\mu}=\beta(g(\mu))\ . \tag{49}$$

This equation is known as the Callan–Symanzik equation (Callan, 1970), (Symanzik, 1970).

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ПОПРАВКИ ПРОПАГАТОРОВ КВАНТОВОЙ ЭЛЕКТРОДИНАМИКИ

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РУБРИКА ГРНТИ: 27.35.00 Математические модели естественных наук и технических наук. Уравнения математической физики:
27.35.57 Математические модели квантовой физики,
27.35.59 Методы теории возмущений

ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В данной статье обсуждается проблема квантовых поправок к пропагаторам в квантовой электродинамике (КЭД).

Методы: Для поправок к пропагаторам в КЭД использовалось уравнение Дайсона – Швингера.

Результаты: Наблюдаемые величины в QED конечны.

Выводы: Расхождения в КЭД можно избежать, соответствующим образом переопределив физические величины.

Ключевые слова: квантовая электродинамика, квантовая теория поля, ренормализационная группа.

КОРЕКЦИЈЕ ПРОПАГАТОРА КВАНТНЕ ЕЛЕКТРОДИНАМИКЕ

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Универзитет у Београду, Институт за нуклеарне науке „Винча“ - Национални институт Републике Србије, Београд, Република Србија

ОБЛАСТ: математика
ВРСТА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: У раду се разматра проблем квантних корекција пропагатора у квантној електродинамици (QED).

Методе: Коришћена је Дајсон-Швингерова једначина за корекцију пропагатора у QED-у.

Резултати: Посматране количине у QED-у су коначне.

Закључак: Дивергенције у квантној електродинамици могу се избећи редефинисањем физичких величина на одговарајући начин.

Кључне речи: квантна електродинамика, квантна теорија поља, ренормализациона група.

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FROM THE EARLY DAYS OF UNMANNED AERIAL VEHICLES (UAVS) TO THEIR INTEGRATION INTO WIRELESS NETWORKS

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FIELD: Telecommunications
ARTICLE TYPE: Review paper

Abstract:

Introduction/purpose: This paper provides an overview of Unmanned Aerial Vehicles (UAVs) from their early days to their integration into modern wireless networks.

Methods: It analyzes, synthesizes and compares the UAVs development technologies throughout their history with significant aspects of their integration in wireless communication networks.

Results: Important aspects of wireless communications as one of the key technologies for UAVs are presented. Next, energy efficiency as a research path for UAVs is considered. The paper also emphasizes the present state in this area as well as what the future of UAVs in communications will be.

Conclusion: UAVs are important not only for widespread military usage in various combat operations and warfare environment, but also for other purposes such as their integration in 5G networks.

Key words: unmanned aerial vehicles (UAVs), drone swarm, Military Internet of Things (MIoT).

Introduction

Unmanned aerial vehicles (UAVs), also known as drones, are aircraft piloted by remote control without human on board. Embedded

computer programs are included, too. A drone tends to be defined in different ways. Two of them are as follows:

- "An unmanned aircraft or ship guided by remote control or board computers" (Meriam Webster's America's most-trusted online dictionary for English word definitions and meanings).
- "A drone in technological terms is an unmanned aircraft. Essentially, a drone is a flying robot that can be remotely controlled or fly autonomously through software controlled plans in their embedded systems, working in conjunction with on board sensors and GPS" (Internet of Things Agenda).

UAVs have enormous potential in enabling new applications in various areas ranging from aerial inspection, photography, precision agriculture, traffic control, search, package delivery, telecommunications, medicine, surveillance, etc. Emerging technologies can benefit from significant potential of UAVs equipped with cameras, sensors and GPS receivers in delivery Internet of Things (IoT) services from great heats, creating an airborne domain of the IoT. Also, the Military Internet of Things (MIoT) represents a class of the Internet of Things for combat operations and warfare. On the other hand, the military IoT could be treated as an internal network with a group of distributed smart objects such as military vehicles, weapons, soldiers, equipment, etc. interconnected with the existing military infrastructure, command and control systems. However, there are many issues to be resolved before the effective use of UAVs can be made including security, privacy, and management.

Background

In should be noted that the earliest military drones appeared in the mid-1850s. The conception dates back to 1849 during the war (see Table I) between Austria and Venice. Unmanned balloons with explosives were used. The Austrian forces launched around 200 incendiary balloons with 11 kg to 14 kg bombs each. It is interesting to note that only one bomb found its mark, while most of the balloons were blown away due to a change in wind direction. From the point of view of military technology, the use of balloons does not meet the current definitions of drones.

Table 1 – UAVs background
Таблица 1 – Сведения о беспилотных летательных аппаратах
Табела 1 – Историјат беспилотних летелица

No.	NAME	YEAR	REASON	DESIGNED BY	CHARACTERISTICS
1.	Earliest military drones	1845-1850	The war between Austria and Venice	Austrian forces	Unmanned balloons equipped with explosive
2.	Gyroplane	1905	Work on the gyroplane	Louis Breguet with his brother Jacques and under the guidance of Charles Richet	Forerunner of the helicopter with flexible wings
3.	Quadcopter configuration of drones	1907	All UAVs are drones	Louis Breguet with his brother Jacques and under the guidance of Charles Richet	Rotary-using aircraft that has 4 main rotors/propellers controlled or auto guided
4.	Drone by Ruston Proctor	1916	Aerial target	Ruston Proctor	Used against zeppelins
5.	Archibald Low system	1917	Radio guidance system	Archibald Low	First wireless rocket
6.	Kettering Bug	1917	To represent “aerial torpedo”	U.S. Army	Gyroscopic control intended to represent “aerial torpedo”
7.	OQ-2	1930	Radio control system	Walter Righter	Small radio-controlled aircraft model
8.	Queen bee	1935	Radio control	British radio control	Radio-controlled target drone
9.	ID-2D-1 Curtiss TD-2D-1	1942	Reverse-engineered	Americans	Pulse jet-powered unmanned aerial drones
10.	A V-1 'Doodlebug'	1944	Flying bomb	German army	simple autopilot to control altitude and air speed
11.	SR-71 Blackbird	1950	Spy plane	Mach strategic reconnaissance aircraft developed and manufactured by Lockheed Martin Corporat.	Long-range, high altitude

No.	NAME	YEAR	REASON	DESIGNED BY	CHARACTERISTICS
12.	Ryan 147BS	1950	Jet-powered drone	Ryen Aeronautical	To recover any information gathered
13.	HAL SOL	1980	Alternative power source for drones	Sponsored by the CIA	Solar-powered aircraft
14.	RQ2 Pioneer	1986	Building an inexpensive drone for fast operations	A join project by the U.S. and Israel	Medium-sized reconnaissance aircraft
15.	Versions of UAVs	1990	Mini and macro	AeroVironment	Mini and macro Predator version
16.	Predator	2000	To lunch missiles	General Atomics	Mini and macro versions of UAVs
17.	Raven, Wasp, Puma	After 2000	Small-sized fixed-wing drones	AeroVironment Inc.	Fixed-wing surveillance drones
18.	Commercial drone	2006	First commercial drone permit was issued	FAA	Pivotal year of the history of drones, with consumer application slow to start and with a small number of people applying for permits in the first few years
19.	Drone-innovation	2006-2015	Commercial interest	A lot of different manufacturers	As delivery vehicles
20.	Operation rules of small UASs	2016	Operational rules	FAA	Use of small devices with aircraft weight less than 25 kg (small unmanned aerial system UASs)
21.	National program	2017	National program “Drone integration pilot program”	FAA	To explore the expanded use of drones including beyond visual line of sight flight, night time operations and fight over people

In 1907, an early development of this technology appeared, called the quadcopter configuration. That year, Louis Breguet (Figure 1) and his brother together with the help of French physiologist Professor Charles

Richet (Figure 2), developed a gyroplane, the forerunner of the helicopter. It should be noted that in 1905 Louis Breguet with brother Jacques and under the guidance of Charles Richet began work on a gyroplane, the forerunner of the helicopter.

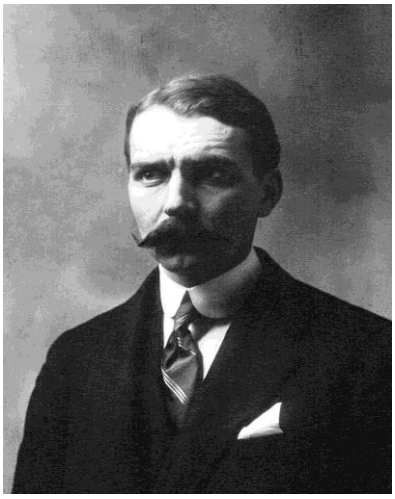

Figure 1– Louis Charles Breguet (Wikimedia Commons, 2021a)
Рис. 1 – Луи Шарль Брегe (Wikimedia Commons, 2021a)
Слика 1 – Луи Шарл Брегe (Wikimedia Commons, 2021a)

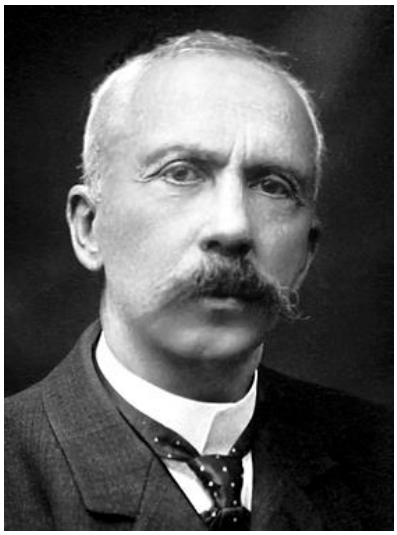

Figure 2 – Charles Robert Richet (Wikimedia Commons, 2021b)
Рис. 2 – Шарль Роберт Рише (Wikimedia Commons, 2021b)
Слика 2 – Шарл Роберт Рише (Wikimedia Commons, 2021b)

British engineer Archibald Low (Figure 3) developed a radio guidance system in 1916 and during Word War I, he used it in the radio-controlled plane called the Ruston Proctor Aerial Target.

Figure 3 – Archibald Montgomery Low (A. M. Low) (Wikipedia, 2021)
Рис. 3 – Арчибальд Монтгомери Лоу (А. М. Лоу) (Wikipedia, 2021)
Слика 3 – Арчибалд Монгомери Лоу (А. М. Лоу) (Wikipedia, 2021)

In 1917, Archibald Low, who was named the father of radio guidance systems, invented the first wireless rocket together with his research group. After this, the U.S. Army built the Kettering Bug with gyroscopic controls and intended to present an "aerial torpedo" (Figure 4).

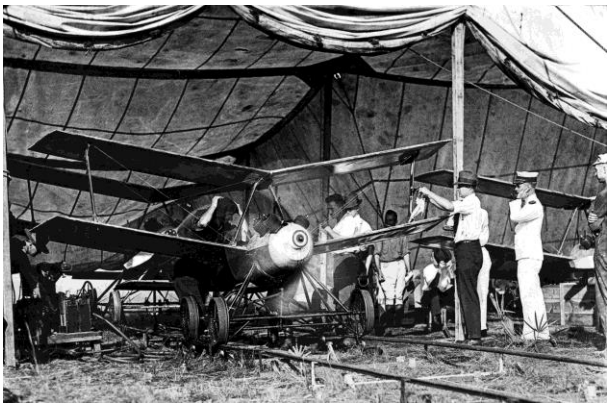

Figure 4 – Photograph of the Kettering Bug prototype (Wikimedia Commons, 2021c)
Рис. 4 – Фотография прототипа «Жука» Кеттеринга (Wikimedia Commons, 2021c)
Слика 4 – Фотографија прототипа „Кетеринг Буг" (Wikimedia Commons, 2021c)

In the 1930s, the OQ-2 was a small radio-controlled aircraft model designed by Walter Righter. UAV technological developments continued. The U.S. Navy began experimenting with radio-controlled aircraft. The British developed “Queen Bee” which is a radio-controlled target drone also believed to have led to “drone” for radio-controlled unmanned aircraft. The first war-produced UAV product in the U.S. was a remote-controlled model airplane developed by British actor Reginald Denny and Walter Righter in the 1930s. Edward M. Sorensen was an inventor of a radio-controlled aircraft that could fly out of sight. He patented a ground terminal to track the movements of the airplane. The significance of this event should be noted because the early aircraft could only operate within the visual sight of the controlling pilot. The “Doodlebug” of the German army was the most notable event of the Second World War with regards to drones. This aircraft was the world’s first missile. Its guidance system used a simple autopilot to control altitude and air speed.

The next big step in drone technology occurred during Vietnam War which saw the first widespread deployment and use of drones as dedicated UAVs.

In the late 1950s, the U.S. spy plane, the manned SR-71 Blackbird, was still in development, while spy satellites were also not ready for deployment. Specialized UAVs were needed to safely gather information in control areas. SR-71 Blackbird was a long-range, high altitude strategic reconnaissance aircraft developed and manufactured by Lockheed Martin Corporation. (Figure 5).

Figure 5 – Lockheed Sr-71 (Wikimedia Commons, 2021d)
Рис. 5 – Lockheed Sr-71 (Wikimedia Commons, 2021d)
Слика 5 – Локид Ср-71 (Wikimedia Commons, 2021d)

Some models did exist, like the Ryan 147BS, but they were parachuted to the ground to gather information. Ryan's Model 147BS is a jet-powered drone, unmanned aerial vehicle produced and developed by Ryan Aeronautical from the earlier Ryan Fireface target drone series. The need for drones exists in many countries who explore the use of UAVs for different applications. New drone models are becoming more and more sophisticated. As for design, they focus on improving the height at which the drones could safety operate. Thanks to transistor technology, radio-controlled components are minimized enough for serving to civilian customer purposes.

In 1980, the U.S. began the UAV Program with the aim of building an inexpensive drone for fast operations. The development of the RQ2 Pioneer was the result of a joint project of the U.S. and Israel in 1986. It was a medium-sized reconnaissance aircraft (Figure 6).

Figure 6 – RQ-2 Pioneer on launch rail 1 (Wikimedia Commons, 2021e)
Рис. 6 – RQ-2 «Пионер» на пусковой установке 1 (Wikimedia Commons, 2021e)
Слика 6 –Пионир RQ-2 на стратној шини 1 (Wikimedia Commons, 2021e)

During this period, drone developers were focused on alternative power services for drones, where the main service was solar power. This led to some interesting solar-powered drones called AERO-Vironment HAL SOL. The High Amplitude (AAL SOL) Solar-powered unmanned aircraft was sponsored by the CIA in 1980s as the first solar-powered aircraft. Mini and micro versions of UAVs were introduced in 1990, while the Predator drone was introduced in 2000.

A number of small-sized, fixed-wing surveillance drones such as Raven, Wasp and Puma, developed by AeroVironment Inc., were

developed after 2000. Raven, for example, is used in many countries, with tens of thousands of units deployed (Figure 7).

Figure 7 – RQ-11 Raven (Wikimedia Commons, 2021f)
Рис. 7 – RQ-11 Ворон (Wikimedia Commons, 2021f)
Слика 7 –Гавран RQ-11 (Wikimedia Commons, 2021f)

Another year in the history of drones was 2006 when the first commercial drone permit was issued. However, the number of people applying for permits in the first year was small. The huge expansion in drone innovation was evident in the last 10 years in commercial interest, too. For example, in the early 2010s, drones were used not only as military vehicles, but also as delivery vehicles. Around 1000 commercial drone permits were issued in 2015 and a demand for drones has continued to grow exponentially. The year 2010 might just be the so-called “golden age of drones”. The number tripled one year later. As a result of merging radio-controlled aircraft and smartphone technology, equipping drones with cameras is a new commonplace in commercial photography and videography. In 2013, a group of researchers examined emerging fields challenging for military: the buildup of ice on drones and other unmanned aerial vehicles. UAVs were not outfitted with protection to eliminate ice buildup. The prototype of the system was tested in 2015. Since then, the technology has been tested regularly in wind tunnels and on board during UAV flights. In 2016, the U.S. Federal Aviation Administration (FAA) released the operational rules for routine civilian use of small UAVs with aircraft weight less than 25 kg. In November 2017, the FAA launched the national program “Drone Integration Pilot

Program" to explore the expended use of drones including beyond visual line-of-sight flying, night-time operations, and flights above people. Drones are becoming very attractive not only because of their fast deployment and low cost, but also because of their ability to hover (Hayat et al, 2016, pp.2624-2661). The size of air drone-cells can be adjusted by changing their altitude, transmission power antenna directivity, and other parameters, providing more adaptability to unstable traffic loads and variable user distributions (Ferranti et al, 2018, pp.1-12). Supporting aerial users with cellular networks goes back to the 2000s with the use of the global system for mobile communication (GSM) 2G (Goddemeier et al, 2010, pp.1760-1765). Later, UAV flight tests were conducted over 3G Universal Mobile Telecommunication System (UMTS) networks. The 3G UMTS network could provide a possible solution for no safety-critical communications for aerial users with moderate speed and altitude of 1220m (Gonzalez et al, 2011. pp.240-248).

Next, 4G Long Term Evolution (LTE) is promising to support aerial users and UAV applications. LTE achieved the best performance in terms of latency and jitter with round trip time of 127 ms and a standard deviation of 48 ms for the worst case scenario (Afonso et al, 2016, pp.4-11). Such results demonstrated the feasibility of UAV operations over the LTE network with a low altitude of up to 100m.

The Third Generation Partnership Project (3GPP) investigation has proved that the existing LTE networks support the UAV deployment with low density and low altitude without need of major changes. As the number of UAVs grows, it is of importance to develop new technologies to enable cellular-connected UAVs in term of 3-D aerial coverage and effective air-ground interference migration.

In 2017, the technology called D.ICE was commercialized by the university in Trondheim. With UAVs, just as with larger aircraft, the accumulation of ice during flight on wings, propellers, and tails can make it hazardous to fly and even cause them to crash. Frozen water on wings increases their weight thus reducing lift and can cause an aircraft to stall. Ice on the propeller can increase drag. Sensors can lock up interfering with the autopilot's ability to gauge speed and altitude.

Icing on UAVs is a relatively new field of research with "unknown parameters". The electro thermal panel can be embedded in UAVs during the manufacturing process or attached to the existing wings. D.ICE uses two algorithms for icing detection. One is a thermal response from the heating zones; the other involves an aerodynamic approach in which the system estimates relevant parameters such as lift and drug and infers if they have degraded due to icing.

Basic requirements

Wireless communication is one of the technologies for UAVs. The reason is very simple. On the one hand, UAVs need to exchange information with a remote pilot, nearby aerial vehicles and air traffic controllers in order to provide the safe, reliable, and efficient flight operation. The general name for it is Controlled Non-Payload Communication (CNPC) (ITU, 2009). On the other hand, UAVs have to transmit and/or receive mission related data (areal image, high speed video, UAV operators, end users, ground gateway). This is payload communication.

There are three CNPC types required for ensuring safe UAV operations communication:

- Communication for UAV Command and Control,
- Communication for Air Traffic Control, and
- Communication Supporting “Sense and Avoid”.

The communication requirements specified by the Third Generation Partnership Project are shown in Table 2.

CNPC is of low data rate, for example in the order of 60-100 kb/s for both downlink (DL) and uplink (UP) directions. On the other hand, reliability of less than 10^{-3} packet error rate and latency of less than 50 ms are required (Table 2). The communication requirements of CNPC links are similar for different types of UAVs due to their common safety - those for payload data are highly application-dependent. Compared to CNPC, UAV payload communication is characterized by much higher data requirements.

Table 2 – UAV communications requirements specified by 3GPP (3GPP, 2017)
Таблица 2 – Требования к системе связи беспилотных летательных аппаратов (БПЛА), предписанные 3GPP (3GPP, 2017)
Табела 2 – Захтеви за комуникацију беспилотних летелица наведени у 3GPP (3GPP, 2017)

	DATA TYPE	DATA RATE	RELIABLITY	LATENCY
UL (GROUND STATION TO UAVs)	Command and control	60-100 kbs	10^{-3} packet error rate	50ms
DL (UAVs TO GROUND STATION)	Command and control	60-100 kbs	10^{-3} packet error rate	-
	Application data	Up to 50 kbs	-	Similar to terrestrial user

For example, to support the transport of a full high-definition (FHD) video from the UAV to the ground user, the transmission rate is about several Mb/s, while for a 4K video, it is higher than 30 Mb/s.

Influence of wireless communications

Wireless technology is necessary for providing seamless connectivity throughput with high reliability in the 3-D space when taking into consideration air-to-air and air-to-ground connections. The most important communication technologies are: direct line, satellite, ad hoc network, and cellular network. These communication technologies are used for military systems and applications in various combat operations, too. For example, applications for military uses involve: reconnaissance, armed attacks, targets for military training, etc.

A direct line is used between an UAV and its associated ground node over, for example, the unlicensed 2,4 GHz band. It is direct point-to-point communication with a simple, low cost, limited range, low data rate, vulnerable to interference and non-scalable. The ground node can be a remote controller, a station etc. It is limited to LOS communication. In urban areas, communication can be easily blocked by trees or high buildings. As a result, this gives low reliability as well as low rate. The ground node needs to connect to a gateway for enabling the Internet access of the UAV. One such solution is insecure and vulnerable to interception and jamming. It should be noted that a solution with direct line communication cannot be a scalable solution for supporting large scale deployment in future applications.

Satellites serve to link data transmitted between widely separated UAVs and ground gateways. This is of importance for UAVs above the ocean and also in remote areas in the case when terrestrial network (Wi-Fi or cellular) coverage is not of practical use. In addition, satellite signals are used for navigation and localization of UAVs. As for disadvantages, there are some of them. First of all, propagation loss and delay are significant because of long distances between satellites and low altitude UAVs/ground stations. Next, UAVs have stringent size, weight, and power constraints. Finally, high operational costs represent one kind of inconvenience for wider use.

Each device in a mobile ad hoc network (MANET) can move over time and its line conditions may change frequently with other devices. Two applications of MANET are vehicular ad hoc network (VANET) and flying ad hoc network (FANET) for supporting communications among

high-mobility ground vehicles and UAVs in 2-D and 3-D networks, respectively (Bekmezci et al, 2013, pp.1254-1270).

FANET is unable to provide a scalable solution for serving massive UAVs deployed in a wide area. The platform realizes a reliable routing protocol over the mobile network with dynamic and intermittent link connectives among flying UAVs.

Today, there is a growing interest in leveraging the existing and future-generation cellular networks for enabling UAV-ground communication (Zeng et al, 2018, pp.120-127).

Both CRC and payload communication requirements for UAVs can be met regardless of the density of UAVs and their distances with the corresponding ground nodes. There are scenarios where cellular services are not available (remote areas, sea, desert, forest). In this case, direct links, satellites and FANET are used to support UAV communication beyond the terrestrial coverage of cellular network. Thus, it is proposed that future wireless networks have an integrated 3-D architecture with UAV-to-UAV, UAV-to-Satellite and UAV-to-ground communication. In such a hybrid network, each UAV is enabled with one or more technologies to exploit rich connectivity diversity.

Also, it is important to emphasize that wireless communications with UAVs involve several typical use cases: UAV-aided ubiquitous coverage, UAV-aided relaying, and UAV-aided information dissemination/data collection. In the first use case, UAVs provide seamless coverage within the serving area, which is suitable for fast service recovery after infrastructure failure, as well as base station offloading in the hotspot application scenario. Next, in the second use case, UAVs connect two or more distant users or user groups thus supporting military operations, e.g. between the frontline and the headquarters, as well as enable big data transfer between data centers. Finally, in the third use case, UAVs provide periodic sensing and information multicasting.

Communication on physical layer

Unmanned aerial vehicle-drone networks are applied in the case of unexpected and temporal events. Each drone has wireless transceivers to communicate with the ground user equipment (UE) and other drones. Drones consist of equipment for receiving, processing, and transmitting signals in order to complement pre-existing cellular systems. In that way, the communication infrastructure becomes reinforced. This case can be of importance from the emergency and safety point of view (Milicevic & Bakmaz, 2020).

Today, the key technologies are: multiple-input multiple-output (MIMO), millimeters wave (mmWave) communication, non-orthogonal multiple access (NOMA) transmission, and cognitive radio (CR).

MIMO is one of the most important technologies when dealing with UAV military communications, because of command and control messages which require low latency and high reliability for application data such as, for example, video streaming. The beam forming gain provided by massive MIMO depends on the accuracy of channel slot information for all served users at each ground base station.

Energy efficiency as an active research field

The need to deal with energy efficiency was driven by:

a) The need to reduce the operation cost and green gas emission and
b) The importance to use the battery for different types of devices.

Energy-efficient UAV communications were focused only on reducing communication-related energy consumption of either the ground nodes (Zhan et al, 2018, pp.328-331) or the UAV (Li et al, 2016, pp.1377-1386).

Taking into consideration the UAV's propulsion energy consumption, there are research interests on energy efficient UAV communications. This invokes design problems due to the new tradeoff between minimizing the UAV propulsion energy consumption versus maximizing the communication throughput.

State-of-the-art UAVs

For the energy efficient trajectory plan of a drone, it is very important to extend its service time. Due to the limited computing ability of a single drone, multiple drones are worth considering in order to simultaneously provide computing services, where the movement control, cooperation and the resource allocation of multiple drones require elaborate design.

Today, UAVs have an exponential growth due to significant technological advances enabling numerous applications ranging from package delivery, traffic control, and video streaming to disaster recovery. Non Terrestrial Networks (NTNs) using UAVs in terms of high-altitude platforms and usage constellations of Low Earth Orbit satellites is going to be realized to provide global Internet service among many others.

UAVs have a variety of applications in areas such as public safety, IoT, caching edge computing and smart cities, as well as in man-made and natural disasters like fires, floods, and earthquakes, providing wireless services to remote and unconnected areas. UAVs also assist ground wireless networks such as D2D communications and mmWave communications. Other applications include their usage in small and power limited devices for healthcare and transportation as well as for high data rate and low latency required in virtual reality applications. Also, the applications of UAV user equipment (UE) in scenarios of surveillance, package delivery, transportation, and remote sensing are of importance.

Mobile devices have become a very significant component of military operations, especially taking into account operations at the tactical edge. This implies that important portions of communications and processing are executed on resource-constrained and bandwidth-limited platforms and networks. One of the most critical aspects in military operations is providing the right information to the right person at the right time. A factor that simplifies searching for stored images in the cloud is that they may be processed before enabling quick search. The decision of where to do the process depends on the state of the military system, energy requirements, the quality of information objectives, and on what has been requested. As for video processing, one of the main problems is labeling all stored images/videos as fast as possible. When videos have been filtered by time and place, there are two steps for labeling, i.e., prime extraction and detection.

Future of UAV communications

There are still many open issues related to the performing UAV communications in 5G systems. For example, in certain use cases, there can exist some dissipations and barriers between UAVs and ground stations. In UAV-enabled multi-user non-orthogonal multiple access (NOMA) systems, the optimal user clustering and user-pairing algorithms are underexplored fields.

It should be noted that successive interference cancellation (SIC) relies on the channel state information at both the receivers and the transmitters to determine the allocated power for each receiver and the decoding order. One of possible problems is to eliminate the interlayer interference caused by multiplexing in the power domain. Next, the communication distance between the UAV and the ground user equipment would vary constantly based on the real-time requirements.

Finally, the SIC decoding order determined by the received signal strength varies with the drone's location.

To provide seamless communication service to ground users over a wide area, a swarm of UAVs constructs a multihop network. Such architecture has centralized coordination enabled by ground infrastructure with computing capabilities (Campion et al, 2018, pp.903-908).

The drawback is a round-trip air-ground delay for UAV coordination. Also, the ground infrastructure is heavily loaded when the number of UAVs in a swarm becomes large. An alternative for a UAV swarm is UAV-to-UAV communication. Here the infrastructure, for example a cellular network, offers the back-bone connectivity between the aerial networks, between UAVs (Zeng et al, 2018, pp.120-127). Some common technical features can be provided, including moveable wireless devices, long communication distance between nodes, a sufficiently high data rate, minimized communication delay, and line of sight affected by weather conditions. Currently, 5G is being applied into commercial use. Drone swarms also play an important role in 5G networks (Figure 8).

They may have to deal with huge data flow with low latency. To meet this demand, some communication technologies are considered for UAV swarms such as millimeter-wave, NOMA and cognitive radio (CR) (Saleem et al, 2015, pp.15-31).

Many academic and standardization groups have proposed the incorporation of CR and UAV communication systems to increase the spectrum opportunities (Saleem et al, 2015, pp.15-31).

This concept constitutes a promising network architecture that allows the coexistence of UAVs with terrestrial mobile devices working in the same frequency band.

The flexible deployment and strong line of sight links of UAVs are expected to make them an important component of future 5G and beyond wireless networks towards the provision of ubiquitous connectivity at any time. Business spectrum sharing among the UAVs and the fixed network infrastructure and the introduction of aerial networks imply additional challenges that need to be addressed. In particular, the energy supplied to UAVs has been identified as one major issue in aerial networks, since apart from the possibility of communication interruption, the possibility of physical damage is also looming. To deal with this problem, the idea of strategically deployed charging stations in urban and rural areas has been recently proposed in the literature. As UAVs gain ground in mobile communications and the

number of UAV operations is expected to increase, limited places in charging stations should be allocated efficiently.

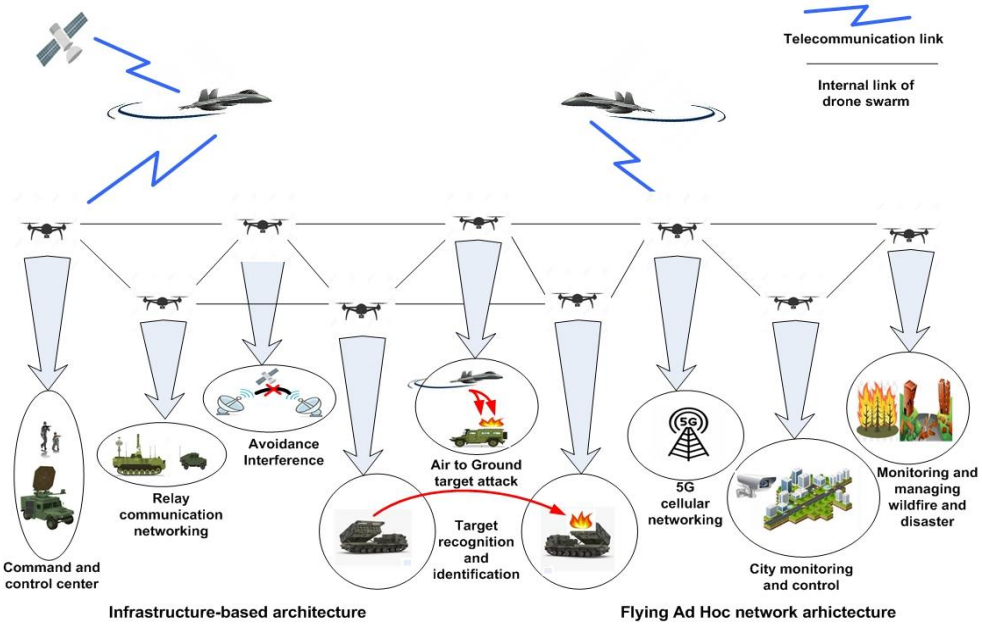

Figure 8 – Drone swarm applications: possible scenario.
Рис. 8 – Приложения для управления роем дронов: возможный сценарий
Слика 8 – Могући сценарио примене ројева дронова

Finally, drone swarm control cooperative missions could be accomplished via control among different military combat and communication and control systems and applications intended for combat operations and warfare (Figure 8). Today militaries are moving ahead with attacks of swarming drones. For example, drones in swarms can be equipped for electronic warfare if needed, or swarms may consist of drones with guns, bombs, and missiles.

Conclusion

UAVs have a long tradition of more than one hundred years of development and exploitation. During this period of time, they have become one of the most important technology items which can be used both on its own and integrated in different systems and applications including cellular networks.

The usage of smartphones reduces the price of microcontrollers, accelerometers and camera sensors, which are devices convenient for

use in fixed-wing aircraft. Advances allowed a drone with 4 or more rotors to be controlled by adjusting the speed of individual rotors. The growing use of unregulated UAVs has also accelerated privacy and physical safety. In that way, the future becomes highly promising. As for drones, it will occur across the segments such as: agriculture, construction and mining, insurance, media, and telecommunications. Drones are expected to become smaller and lighter with much longer battery life and flight time.

Also, there will be developments in improving drone optics. From the civilian point of view, improving flight time allows them to serve as delivery platforms, or to be used in emergency services and for data collections in a number of areas dangerous for humans, such as in power plants, fires, etc. Home security and crowd control are included too. Also, one important thing is miniaturization. As components become smaller and smaller, UAVs will be reduced in size; there will be, for example, microscopic drones in the future. Development in flight control algorithms, machine vision and onboard processing power will enable UAVs to make decisions themselves, rather than to rely on human input. In that way, the reaction time and speed will be improved. The flexible deployment along with strong line-of-sight links of UAVs are expected to make them an important component of 5G, and apart from being used in wireless networks, they are also to become components of various military systems towards the provision of ubiquitous any time connectivity (Li et al, 2019, pp.2241-2263).

Military networks are crucial in carrying out military actions. As images/videos are rich sources of information, the main challenge is to be in a position to issue a query over a large distributed set of devices to find concrete actions or objects of interest. The concrete MIoT solution architecture depends on a specific military scenario and the area of application (Zieliński et al, 2021, pp.36-42).

Finally, energy supply was identified as one of major issues in aerial networks. In order to deal with this problem, the idea of deploying charging stations has been proposed by Z.W. Mekikis and Antonopoulos in 2019. However, UAV operators are expected to increase the limited space in charging stations.

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ОТ СОЗДАНИЯ БЕСПИЛОТНЫХ ЛЕТАТЕЛЬНЫХ АППАРАТОВ (БПЛА) ДО ИХ ИНТЕГРАЦИИ С СЕТЯМИ БЕСПРОВОДНОЙ СВЯЗИ

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РУБРИКА ГРНТИ: 78.00.00 ВОЕННОЕ ДЕЛО:
78.25.00 Вооружение и военная техника;
78.25.31 Системы и средства военной навигации, наведения и управления,
78.25.33 Системы и средства военной связи,
49.00.00 СВЯЗЬ:
49.33.29 Сети связи

ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В данной статье представлена история беспилотных летательных аппаратов (БПЛА) от их создания до интеграции в современные беспроводные сети.

Методы: Проведен анализ, синтез и сравнение развития технологий БПЛА на протяжении всей их истории, с акцентом на значимые аспекты их интеграции в сети беспроводной связи.

Результаты: В статье представлены важные аспекты беспроводной связи как одной из ключевых технологий для развития БПЛА. Также рассматривается энергоэффективность как направление для исследований БПЛА. Помимо вышеперечисленного, в статье описано настоящее состояние БПЛА и их перспективы в будущем.

Выводы: БПЛА играют важную роль не только в различных военных операциях в боевых условиях, где они широко применяются, но они также могут быть полезны и для других целей, таких как, например, интеграция в сети 5G.

Ключевые слова: беспилотные летательные аппараты (БПЛА), рой дронов, военный интернет вещей.

ОД ПОСТАНКА БЕСПИЛОТНИХ ЛЕТЕЛИЦА ДО ЊИХОВЕ ИНТЕГРАЦИЈЕ У БЕЖИЧНЕ МРЕЖЕ

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Miličević, Z. et al, From the early days of unmanned aerial vehicles (UAVS) to their integration into wireless networks, pp.941-962

ОБЛАСТ: телекомуникације
ВРСТА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: У раду је представљен историјат беспилотних летелица (БЛ) – од постанка до интеграције у савремене бежичне мреже.

Методе: Коришћене су анализе, синтеза и упоређивање технологије развоја беспилотних летелица кроз историју са значајним аспектима интеграције у бежичне комуникационе мреже.

Резултати: Представљени су важни аспекти бежичне комуникације, као једне од кључних технологија за БЛ. Разматрана је и енергетска ефикасност као пут истраживања беспилотних летелица. Такође, описује се садашња функција БЛ и предвиђа будућа комуникација са њима.

Закључак: Беспилотне летелице нису важне само за широку војну употребу у различитим борбеним операцијама и ратном окружењу, већ и за друге сврхе, попут интеграције у 5Г мреже.

Кључне речи: беспилотне летелице (БЛ), рој беспилотних летелица, војне интернет ствари.

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BIOMETRIC STANDARDS AND METHODS

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Abstract:

Introduction/purpose: Nowadays, user identification systems play a very important role in modern society. Complex security requirements have led experts to explore ways in which biometric data can be used to identify user identities. This paper presents an overview of biometric standards and methods which can be used to identify users in biometric systems, and therefore to protect information and communication systems.

Methods: This paper deals with the problem of standardization in the field of biometrics. The first part of the paper presents concrete examples of the most widely used biometric standards. The second part of the paper gives an overview of the most used biometric methods.

Results: The obtained results show that the development of biometric systems and biometric sensors contributes to better protection of identity from misuse, because biometric technologies have great potential for improving the security and accuracy of system operation. Biometric systems improve the security of users and also provide much greater precision in establishing identity.

Conclusion: The development of biometric standards should focus on their interconnectivity, as well as on increasing connectivity with other IT standards.

Key words: biometric standardization organizations, biometric standards, biometric sensors, biometric methods.

Introduction

Nowadays, Personal Identification Numbers (PINs) or various passwords are often used for identification purposes. For example, people are asked to identify themselves when withdrawing money at ATMs, logging in on computers, using keys when opening the doors, using codes when entering buildings, typing passwords on the Internet or giving ID, passport or driver's license numbers as proof of identity. All of these methods have various disadvantages (cards and keys can be stolen, passwords can be hacked). In order to precisely identify an individual to minimize current security issues and threats, biometric technics can be used.

Biometrics is a tool that can be used to complement or even replace existing user identification systems based on what the user knows or what he or she possesses. Biometrics is one of the key methods for user recognition because it provides strong security and has great practicality (Ortega-Garcia et al, 2004).

Biometric systems use one's biological and behavioral characteristics which can be distinguished for the purpose of biometric recognition (Jain et al, 2000), (Jain et al, 2004).

There are several biometric technologies that have been used so far: fingerprint- (Lalović et al, 2019), face-, iris-, or vein arm-based (Kumar & Prathyusha, 2009), (Wang & Wang, 2017), electroencephalograms (EEGs), electrocardiograms (ECGs) (Chun, 2016), (Odinaka et al, 2012), and multispectral skin photometrics (MSP). Each of these biological characteristics uses specific biometric sensors.

The development of biometrics for user authentication has led to the development of standards for biometrics. These standards should provide the set of specifications to ensure interoperability with other biometric systems and products (Prabhakar et al, 2003).

This paper gives an overview of the most applied biometric standards as well as biometric methods that can be used to resolve security issues and threats.

Biometric standardization organizations

Each standard should be based on proven results of science, technology (technology) and experience.

Standardization organizations are divided into: formal and informal.

Formal Standardization Organizations (FSOs) develop "de jure" standards, and they form official national standards bodies and internationally recognized bodies. The examples of formal organizations for standardization are:

At the International Development Standard (SDOs) level:

- IEC - International Electrotechnical Commission,
- ISO - International Organization for Standardization, and
- ITU - International Union of Telecommunications.

At the regional level:

- CENELEC - European Committee for Standardization in Electrical Engineering,
- CEN - European Organization for Standardization, and
- ETSI - European Institute for Standardization in Telecommunications.

At the national level:

- JISC - Committee on Japanese Industrial Standards,
- ANSI - US National Standards Institute, and
- BSI - British Standards Institution.

"De facto" standards are developed by informal standardization organizations, usually by business associations and consortia. Some of them are W3C (World Wide Web Consortium), Internet Engineering Task Force and OASIS. JavaCard Forum, BioAPI Consortium and Voice XML Forum represent informal standardization organizations that deal with biometric data.

Formal standardization organizations

JTC1 ("Join Technical Committee 1") is the ISO and IEC technical committee for information technology standards. It has a subcommittee with the task of development of generic biometric standards SC37 ("SubCommittee 37").

This subcommittee has six working groups WG ("Working Group") with a specific area of work:

WG1 - Harmonized Biometric Vocabulary,
WG2 - Biometric Technical Interfaces,
WG3 - Biometric Data Interchange Formats,
WG4 - Biometric Profiles,
WG5 - Biometric Performance Testing and Reporting, and
WG6 - Cross-Jurisdictional and Societal Aspects of Biometrics.

ISO has other technical committees with task of dealing with biometric data. These are TC68 for financial services, JTC1 SC32 for data management and exchange, JTC1 SC17 for cards and personal identification, JTC1 SC29 for encoding audio, image, multimedia and hypermedia records, JTC1 SC24 for computer graphics and images, JTC1 SC27 for IT security techniques, JTC1 SC31 for automatic identification and data acquisition techniques, JTC1 SC36 for IT for learning, education and training, ITU-T SG17.

Informal standardization organizations

The BioAPI consortium is an example of informal organization for biometric standards. It was responsible for development of a common biometric application programming interface. The ANSI standard and the ISO standard are the most famous specifications of this group.

Biometric standards

There are different ways of collection and reproduction of biometric data so the safety of biometric data is crucial (Unar et al, 2014).

The financial sector was the first sector that used biometric standards. However, the development of biometric systems has led the organizations for standardization to introduce new biometric standards which are related to the security of biometric applications and biometric systems.

Nowadays, there are a lot of studies in the field of biometrics such us biometric transaction security and protection of biometric data.

The most popular biometric technical standards founded by SC37 are the Biometric Application Programming Interface (BioAPI) and the Common Biometric Exchange Format Framework CBEFF).

BioAPI

The BioAPI (Biometric Application Programming Interface) standard determines biometric application interfaces, devices and algorithms for distinguishing biometric data and device types.

This standard introduces basic functions of biometric systems, i.e. Enrollment, Verification and Identification. It also introduces an API (Application Program Interface) and an SPI (Service Provider Interface) for programmers and developers. Figure 1 gives the BioAPI's Application Program Interface/Service Provider Interface model.

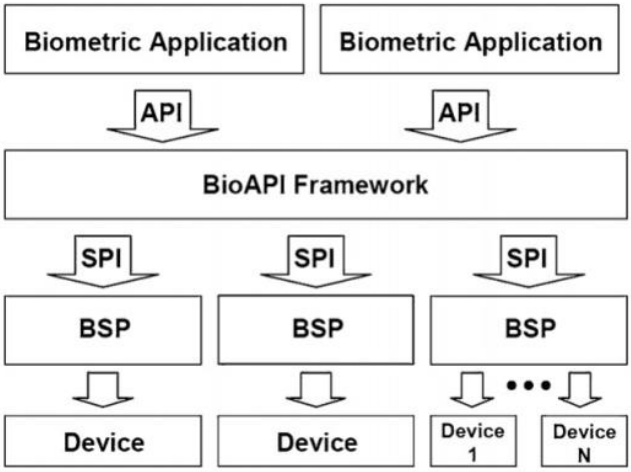

Figure 1 – BioAPI's API/SPI model (Thevenot et al, 2001)
Рис. 1 – BioAPI API/SPI модель (Thevenot et al, 2001)
Слика 1 – Модел BioAPI API/SPI (Thevenot et al, 2001)

CBEFF

The CBEFF (Common Biometric Exchange Format Framework) introduces a set of data elements needed to support biometric technologies in order to provide interoperability between biometric programs and biometric systems made by different manufacturers.

Figure 2 refers to the basic data structure for face, iris, fingerprint, palm, etc.

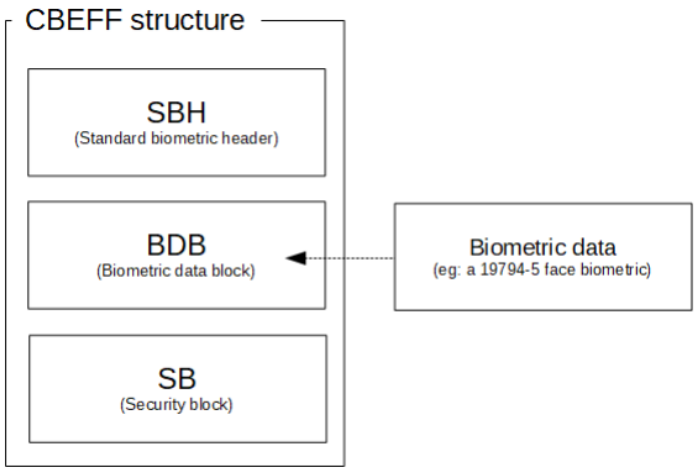

Figure 2 – CBEFF basic data structure (Thevenot et al, 2001)
Рис. 2 – CBEFF базовая структура данных (Thevenot et al, 2001)
Слика 2 –Основна структура података CBEFF (Thevenot et al, 2001)

ACBio

In order to ensure the integrity and confidentiality of transactions, the ACBio standard uses data encryption and digital certificates. It specifies the structure of data for a remote biometric verification.

In the ACBio model, a biometric transaction represents a number of processes executed by the Biometric Process Unit - BPU (e.g. sensor, smart card, comparison device, software running on a personal computer, etc.). Each of them sends relevant security information as a data block called the ACBio instance generated by the BPU.

Biometric sensors

In order to reach the phase of user identification, in terms of protection of information and communication systems, it is necessary to

collect biometric data through biometric sensors that will be compared with the already existing data registered in the system itself.

A sensor is a device that measures physical quantities and converts them into a signal readable by an observer or an instrument. The measured signal can be light, heat, movement, humidity, pressure or any other environmental phenomenon. The output is usually a legible signal to the observer or instrument at the sensor location itself or can be transmitted electronically over the network for reading and further processing.

Sensors have a wide application in virtually all aspects of life, including safety, security, surveillance, monitoring and detection in general (Ortega-Garcia, 2004). Sensors in the industry occupy a central place in process control, monitoring and security. In medicine, sensors also occupy a primary place because they are used to diagnose and monitor physiological changes in patients.

There are several sensor classifications by different authors and experts (Thevenot et al, 2001). Some are very simple and some very complex. According to one classification of sensors, they are divided into active and passive ones. Active sensors are those that require an external excitation signal or power signal, while passive sensors, on the other hand, do not require any external power signal and directly generate a signal response. The second type of classification is based on the means of detection used in the sensor. Some of the detection methods are electrical, biological, chemical, radioactive, etc. The following classification is based on the phenomenon of conversion, i.e. input and output. Some of the common conversion phenomena are photoelectric, thermoelectric, electrochemical, electromagnetic, thermo-optical, etc. (Maček et al, 2015). Finally, sensors can be classified into analog and digital ones. Analog sensors produce an analog output, i.e. a continuous output signal. Digital sensors, unlike analog sensors, work with discrete or digital data. The data in digital sensors used for conversion and transmission are digital in nature (Lalović, 2018).

Research and development of biosensors is becoming an increasingly developed discipline, because simple, fast, cheap, highly sensitive and highly selective biosensors contribute to progress in all aspects of life. For example, in a new generation of medicine, such as individualized medicine and ultrasound detection, an on-site sensor marks diseases. Some of the conventional biosensors and biosensing techniques from the point of view of smart biomaterials are: biosensors based on SPR (surface plasmon resonance), biosensors based on FRET

(fluorescent glucose biosensors) and biosensors based on AuNP (gold nanoparticles).

Research related to biosensors is interdisciplinary. For example, advances in surface chemistry provide new methods for designing target molecule recognition systems. In the future, advances in nanofabrication technologies promise not only the construction of new transducers, but also the miniaturization and integration of high-bandwidth biosensors. Therefore, the development of innovative biosensors requires interdisciplinary efforts outside conventional specialties. The combination of a lot of interdisciplinary knowledge will accelerate the development of biosensors and contribute to the revolution in the biomedical fields.

Biosensors are analytical devices that convert biological signals into electrical signals. Essentially, biometric sensors are highly specific, independent of physical parameters such as pH and temperature, and must be reusable.

The development of biosensors, as well as biosensor materials, transduction devices and immobilization methods, requires multidisciplinary research in chemistry, biology and engineering. The materials used in biosensors are categorized into three groups based on their mechanisms: a biocatalytic group containing enzymes, a bioaffinity group including antibodies and nucleic acids, and microorganisms containing microorganisms.

Biometric methods

Biometric devices perform data acquisition by receiving data from one of the sensory receptors in the form of a sensation that occurs in or on the human body and converts it into analog or digital signals that are used for further processing (Lalović et al, 2017). The data thus collected can be used to identify people. Individual biometric data are unique for each person and can be used to identify persons, both in the civil sector, e.g. in health care, educational institutions, companies, as well as in military, police and state institutions in order to protect their own resources. Biometric authentication (i.e. real authentication) is used in information technologies as a form of user identification and access control to protected resources.

Verification involves performing a one-on-one biometric comparison to provide access to either physical assets, such as a room or building, or digital assets, such as a smartphone, computer application, computer network, or database. For this purpose, biometric data is increasingly used as a replacement for traditional passwords and PIN codes to

improve access control. By comparing a living biometric sample of an individual with one reliable stored sample, the identity of the person is determined (Lalović et al, 2015). This saved sample can be located either in a central database, a smartphone, or as a token on a credential, such as an ID smart card (Lalović et al, 2016a).

There are different methods for biometric data acquisition and user authentication. Each of the methods of biometric identification has something specific:

Face recognition - Of the various methods of biometric identification, face recognition is one of the most flexible, even when the subject is not aware of the scan. This method of identification can search masses of people who have spent only a few seconds in front of a “scanner” - that is, an ordinary digital camera. Facial recognition systems work by systematically analyzing specific features that are common to all - the distance between the eyes, the width of the nose, the position of the cheekbones, the line of the jaw, the chin and so on. These numerical quantities are then combined into one code that uniquely identifies each person (Al-Maadeed et al, 2016).

Fingerprint identification - Fingerprints remain constant throughout life. In more than 140 years of comparing fingerprints around the world, it has not been discovered that two fingerprints are similar, even in identical twins. Fingerprint scanners are installed in PDAs, mobile phones and laptops, so scanning technology is also simple. Fingerprint identification includes comparison of ridge and groove fingertip samples, as well as minutiae (ridge characteristics that occur when the ridge splits in two, or ends) with biometric fingerprint samples in the database (Bhardwaj et al, 2017), (Lalović et al, 2016b).

Palm geometry biometrics – Palm geometry readers work in more extreme environments, do not require clean conditions and form a small data set. It is a common method of authentication in industrial environments.

Retinal scan - There is no way to fake the retina in the literature. The pattern of blood vessels on the back of the eye is unique and remains the same throughout life. However, it takes about 15 seconds of careful concentration for the scan to be of good quality. Retinal scanning is standard in the military and government sectors.

Iris Scanning - Like retinal scanning, iris scanning also provides unique biometric data that is very difficult to fake and remains unchanged throughout life. There are ways to encode biometric data to scan the iris in such a way that it can be securely transmitted in the “barcode” format (Belcher & Du, 2008).

Signature - A signature is another example of biometric data that is easy to collect and not physically intrusive. Digitized signatures are sometimes used, but usually do not have sufficient resolution to ensure authentication.

Voice Analysis - Like face recognition, voice biometrics provides a way to authenticate an identity without the subject's knowledge. But it has a big drawback, because it is easy to fake.

EEG authentication - uses an electrophysiological system to monitor brain activity. This technology is very popular and can be used without any side effects on the brain (Chen et al, 2016), (Tot et al, 2021), (Nakamura et al, 2017).

Conclusion

Given the significant advances in science and technology, such as basic developments in micro / nanotechnology, wireless communications, information technology and biomedical sciences over the past few years, there has been a transformation in this area of biometric systems, and models have been designed and built in a wide range of biosensors and load-bearing sensors.

The development of biometric systems and biometric sensors contributes to better protection of identity from misuse, because biometric technologies have great potential for improving the security and accuracy of system operation. The application of biometric systems improves the security of users, and such systems also provide much greater precision in establishing identity.

Due to the importance of establishing identity, it is necessary to constantly work on improving the system for precise identification, i.e. on improving their performance, either through the development of biometric sensors, or through the improvement of biometric data acquisition methods.

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БИОМЕТРИЧЕСКИЕ СТАНДАРТЫ И МЕТОДЫ

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РУБРИКА ГРНТИ: 50.00.00 АВТОМАТИКА. ВЫЧИСЛИТЕЛЬНАЯ ТЕХНИКА:
50.41.00 Программное обеспечение вычислительных машин, комплексов и сетей
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Системы идентификации пользователей играют весьма важную роль в современном обществе. Сложные требования безопасности побудили экспертов изучить способы использования биометрических данных для идентификации личности пользователя. В данной статье представлен обзор биометрических стандартов и методов, которые могут использоваться для идентификации пользователей в биометрических системах, а следовательно и для защиты информационных и коммуникационных систем.

Методы: В данной статье рассматривается проблема стандартизации в области биометрии. В первой части статьи представлены конкретные примеры наиболее широко используемых биометрических стандартов. Во второй части статьи приведен обзор наиболее часто используемых биометрических методов.

Результаты: Полученные результаты показали, что прогресс биометрических систем и биометрических датчиков способствует лучшему удостоверению личности и предотвращает неправомерное использование идентичности другими лицами, поскольку биометрические технологии обладают большим потенциалом повышения безопасности и точности работы системы. Биометрические системы повышают безопасность пользователей, а также обеспечивают гораздо большую точность при установлении личности.

Выводы: При разработке биометрических стандартов следует сосредоточить внимание на их внутреннюю взаимосвязанность, а также на улучшении их взаимосвязи с другими ИТ-стандартами.

Ключевые слова: организация биометрической стандартизации, биометрические стандарты, биометрические датчики, биометрические методы.

БИОМЕТРИЈСКИ СТАНДАРДИ И МЕТОДЕ

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ВРСТА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: У данашње време системи за идентификацију корисника имају веома важну улогу. Сложени захтеви који се односе на сигурност навели су експерте да разматрају начине на које би биометријски подаци могли бити коришћени за идентификацију корисника. У раду је представљен преглед биометријских стандарда и метода који се могу користити за идентификацију корисника у биометријским системима, чиме би се остварила заштита информационих и комуникационих система.

Методе: Разматрају се проблеми у стандардизацији на пољу биометрије. У првом делу рада наводе се конкретни примери најчешће коришћених биометријских стандарда, а у другом даје преглед биометријских метода које се најчешће употребљавају.

Резултати: Прикупљени резултати показују да развој биометријских система и биометријских сензора доприноси бољој заштити идентитета од погрешне употребе, с обзиром на то да биометријске технологије имају велики потенцијал за побољшање заштите и тачности системских операција. Примена биометријских система повећава заштиту корисника, као и

омогућава бољу прецизност приликом успостављања идентитета.

Закључак: Развој биометријских стандарда треба да се фокусира на њихову међусобну повезаност, као и на чвршћу везу са осталим ИТ стандардима.

Кључне речи: организације за биометријску стандардизацију, биометријски стандарди, биометријски сензори, биометријске методе.

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САВРЕМЕНО НАОРУЖАЊЕ И ВОЈНА ОПРЕМА
СОВРЕМЕННОЕ ВООРУЖЕНИЕ И ВОЕННОЕ ОБОРУДОВАНИЕ
MODERN WEAPONS AND MILITARY EQUIPMENT

Продужење животног века: Велика Британија покреће програм модернизације тенка Challenger 2[1]

Британски тенк *Challenger 2* убрзано губи трку са модерним тенковима. Ради продужења његовог животног века након 2035. године, британска армија покренула је програм модернизације под називом *Challenger 2 LEP*.

Тенк *Challenger 2* је прошао кроз неколико спорадичних модернизација током свог животног века, укључујући програм *Challenger base inspection and repair, Platform Battlefield Information System Application*, *the thermal imaging sustainment project,* као и екстензивна унапређења пре рата у Ираку 2003. године.

Међутим, ова платформа није никада доживела комплетну модернизацију као, на пример, ону која је урађена за амерички тенк M1 Abrams од модела M1A1, M1A2, M1A2 SEPv1, M1A2 SEPv2, и M1A2 SEPv3 стандарда, укључујући и будући M1A2 SEPv4. С друге стране, и немачки тенк *Leopard 2* прошао је кроз разне стандардне модернизације, као што су 2A4, 2A5, 2A6 и 2A7 уз стандарде 2A6M и 2A7V.

Предлог пакета Challenger 2 LEP подразумева потпуно нову куполу и нови топ са глатком цеви 120 mm

[1] Jane's Defence International April 2021

Из британске армије наведено је да ће се након 2025. године тенк *Challenger 2* сврстати у технички застарелу платформу и неадекватну у супротстављању пројектованим претњама. Иако се ради о добро заштићеном тенку, његове способности су прилично деградиране. Поред појаве нових кинетичких пројектила, као што су 3ВМ70 *Vacuum-2* (APFSDST) и нових противтенковских вођених ракета, као што је *9M133M Kornet-M,* возило није ни адекватно наоружано у односу на своје потенцијалне противнике.

Програм *Life Extension Project (LEP)* покренут је 2013. године са намером да се замени опрема која се више не производи и да се продужи животни век тенка без значајне модернизације.Ради тога је британско министарство одбране одобрило два уговора у вредности од 31,23 милиона долара компанијама *BAE Systems* и *Rheinmetall Landsystems* са задатком да развију дигиталне прототипове.

У октобру 2018. године, компанија *BAE Systems* открила је да се концептно возило назива *Black Night,* што сугерише повећане могућности у ноћним борбама. Једна од опционих могућности била је и додавање активног система заштите чији је демонстратор била израелска компанија *Elbit Systems* за активни систем заштите под *називом Iron Fist Light Decoupled (IF-LD)* hard-kill system.

Током јануара 2019. године, компанија *Rheinmetall* приказала је нову опцију модернизације која је знатно обимнија од захтева програма LEP са новом дигитализованом куполом и топом глатке цеви 120 мм компаније *Rheinmetall*.

У јулу 2019. године, формирано је привредно друштво *Rheinmetall BAE Systems Land d (RBSL),* у оквиру компаније *BAE Systems factory,* које је један од добављача оклопних борбених возила 8×8 *Boxer* за британски програм *UK Mechanised Infantry Vehicle*. Након разматрања проширене опције коју је понудио тим RBSL, британска армија је ревидирала своје захтеве и сложила се са понуђеним пројектом који је након тога назван *LEP+.*

Ватрена моћ

Основна промена састојаће се од замене постојећих топова 120 мм *L30A1* са олученим цевима топовима 120 мм *L55A1* немачке компаније *Rheinmetall.* Ради се о моделу топа *L55A1* који се налази на немачком тенку *Leopard 2A7V* са повећаном брзином пројектила и већом пробојности у односу на стандардну верзију топа *L55,* као и у односу на британски топ *L30A1*. Топ *L55A1* има до 20% већу пробојност у односу на стандардну верзију.

Приказ немачког пројектила DN63 APFSDS за топ L55A1

Друга разлика односи се на прелазак са дводелног, односно троделног британског пројектила на једноделни. То ће омогућити Великој Британији употребу комплетне НАТО муниције, укључујући и најновије пројектиле типа *DM63* и *DM73*.

Сједињене Државе потврдиле су да амерички пенетратор *M829A4* са језгром од осиромашеног уранијума такође може бити употребљен као муниција овог топа. Велика Британија тренутно користи пенетратор од осиромашеног уранијума *L27A1 Challenger Armament 3 (CHARM 3) APFSDS* у постојећем топу *L30A1* и вероватно ће желети да задржи право на употребу таквог пројектила и за нови топ.

Употреба стандардног НАТО пројектила подразумевала би уштеде у куповини школске муниције, као и „ратних зрна", али и будући заједнички развој нових типова пројектила.

Муниција ће бити ускладиштена у новом, сада индустријском стандарду, одељку са издувним панелима у случају пробоја куполе. Овај одељак биће пуњен са 15 граната, а додатних 16 граната биће ускладиштено у трупу тенка, што значи да ће тенк имати до 31 гранату. Овакво решење је знатно умањило капацитет од некадашњих 49 граната у претходној верзији тенка, што је било омогућено лакшим складиштењем дводелних граната.

Концепт аутоматског пуњача је одбачен, јер би захтевао пројектовање потпуно новог трупа тенка, а, са друге стране, у британској армији и даље сматрају да је умањење посаде са четири на три члана контрапродуктивно у смислу одржавања и логистике.

Заштита

На новој куполи уводи се нови модуларни оклоп који повећава заштиту возила. Оштећени модули моћи ће се заменити модулима нове оклопне технологије када буду доступни. Инсталација модула је и знатно јефтинија од инсталације комплетне оклопне заштите на куполама.

Нови систем заштите уводи и додатни оклоп appliqué на бочним странама тенка ради заштите против мина, импровизованих експлозивних направа и других претњи. Ипак, постојећа решења додатног оклопа знатно утичу на повећање тежине, па „Лабораторија одбрамбених наука и технологија" убрзано ради на новом лакшем оклопу.

Иако је систем активне заштите један од прерогатива постизања постављеног циља који се односи на преживљавање, нарочито када се ради о одбрани од противтенковских вођених ракета, овај систем неће бити инсталиран на сва возила већ ће она бити опремљена тако да се на њима може инсталирати поменути систем уколико то буде касније захтевано. Тренутно постоји идеја о инсталацији неких 60 система активне заштите.

Британска армија тренутно разматра израелски систем активне заштите *Trophy-HV* уколико буде одлучено да се угради. Иначе, овај израелски систем биће уграђен на амерички тенк *M1A2 SEPv2 Abrams* и немачки тенк *2A7VA1*. Систем је иначе у употреби на израелским тенковима *Merkava Mk 4* који су први пут борбено употребљени у операције *„Protective Edge"* током 2014. године. Током те операције систем *Trophy-HV* је не само пресретао противтенковске вођене ракете и кумулативне ракете већ је указивао и на локацију лансирања која је преко мреже упућивала остале израелске одбрамбене платформе на противдејства.

Покретљивост

Покретљивост као концепт није елемент програма *LEP,* али се разматра у ширем смислу, односно на нивоу унапређења целе флоте тенкова *Challenger 2* која укључује возило за обуку, носач моста *TITAN* и инжењерско возило *TROJAN*. Питање покретљивости биће разматрано у оквиру програма „*Heavy Armour Automotive Improvement Project" (HAAIP),* као и модификација у оквиру планираних сервиса и модернизација „*Maintenance, Repair, and Overhaul Level 4" (MRO4).*

У оквиру пројекта *HAAIP* радиће се стандардизација мотора и вешања на свим типовима тенка *Challenger 2*. Мотор ће бити доведен на стандард *CV12-8a*, суспензија ће бити хидрогасна *(3GH),* а биће имплементиран и електрични хладни стартни систем и унапређен систем за хлађење.

Након завршене модернизације, тенк *Challenger 2* биће знатно тежи, па ће се наћи у класи *MLC100,* што значи да ће то утицати на логистику. С тим у вези, то ће довести до промена у области транспортера и преносних мостова. Проблеме око транспорта прво је имала америчка војска када се

увидело да тенк *M1A2 SEPv3* не може користити постојећа превозна средства и тактичке мостове.

Пројект *HAAIP* неће допринети значајном повећању снаге мотора. Тенк *Challenger 2* иначе нема мотор снаге модерних тенкова, јер износи само 1.200 КС у односу на просек од 1.500 КС, док се данас снага мотора пројектује од 1.800 и 2.000 КС.

Комуникациони и осматрачки системи

У оквиру програма *LEP* очекује се уградња британског тактичког комуникационог система *MORPHEUS*. Са дигитализованом куполом предвиђа се и модернизација система *C4ISR*.

Командирова панорамска осматрачка справа биће *ORION* компаније *Thales,* док ће нишанска справа нишанџије бити *Thales DNGS T3*. Ови уређаји су већ у производњи у Великој Британији за извиђачко возило AJAX, што би поједноставило логистичке захтеве и умањило цену.

План програма

Велики је притисак за покретање програма LEP. Британска тенковска флота се тренутно одржава коришћењем делова са возила која се не користе, али такав процес може трајати само до 2025. године. Британска армија је навела да ће након те године остати без иједног тенка.

Challenger 2 је један од највећих и најтежих тенкова на свету и спада у сам врх најзаштићенијих тенкова

Програм LEP ће омогућити набавку до 190 возила ради опремања две моторизоване тенковске бригаде заједно са одговарајућим средствима за обуку и одржавање. Очекује се набавка 157 класичних тенкова, 33 командна тенка, као и инжењеријских тенкова.

Међутим, с обзиром на мали буџет, не постоји велика вероватноћа да ће бити испуњен циљ модернизације 190 возила.. Као што је навела компанија *Rheinmetall* у свом извештају из 2021. године, реалније је да се модернизује 138 тенкова.

Британска армија разматра и алтернативне планове који укључују лизинг, куповину половних тенкова или локалну производњу немачког тенка *2A7V,* односно америчког тенка *US M1A2 SEPv2,* али и евентуалну набавку нових возила као што је корејски тенк *K2*. Ипак, све поменуте опције су процењене као неизводљиве или политички некомпатибилне са опцијом и захтевима програма *LEP+.*

Велика Британија је последња у низу земаља НАТО-а које су предузеле модернизацију својих тенковских капацитета.

Британски план LEP предвиђа увођење потпуно нове куполе која би продужила животни век тенка *Challenger 2* и након 2035. године.

Немачка

Немачки тенк *Leopard 2* представља узор успешног комерцијалног развоја тенка. Од кад је уведен 1979. године, *Leopard 2* налази се у наоружању чак 19 држава, а ради се о чак 90 разних варијанти за 3.500 произведених и испоручених возила.

Тенк Leopard 2

Немачки тенк је унапређен кроз седам стандардизација. Сваких 5до 10 година рађена је велика модернизација, а 2 до 5 година мања. Велике модернизације биле су означене стандардима од 2*A4*, затим *2A5, 2A6* и

Vučković, D., SAVREMENO NAORUŽANJE I VOJNA OPREMA / MODERN WEAPONS AND MILITARY EQUIPMENT, pp.978-991

најновија *2A7,* које су праћене мањим стандардизацијама као што су *2A6M, 2A6M+, 2A6MA1/2/3, 2A7V, и 2A7A1*.

Захваљујући оваквом приступу Немачка је одржала високи технолошки ниво возила и омогућила својој индустрији велики број уносних уговора, као и одржавање способности овог тенка. Наиме, производне линије за тенк *Leopard 2* нису прекидане преко 40 година.

Најновија унапређења се и даље спроводе, као што су стандарди *2A7V* и *2A7A1*. Последњи стандард укључује топ *L55A1*, који ће бити уграђен у тенк *Challenger 2 LEP*. Стандард *2A7A1* је ознака која ће бити уведена за тенкове стандарда *2A7,* а који ће бити опремљен израелским активним системом заштите *Trophy-HV,* истим којим ће бити опремљен и тенк *Challenger 2 LEP*. Овај систем активне заштите биће уграђен и на тенкове стандарда *2A6A3,* а за сада се планира уградња на 17 возила.

Немачка намерава да настави са континуираним модернизацијама тенка *Leopard 2* све до 2040. године, односно да краја развоја немачко-француског пројекта *Main Ground Combat System (MGCS)* у оквиру којег би био уведен нови тенк за обе земље –Француску и Немачку.

Сједињене Америчке Државе

Сједињене Државе следиле су сличан развојни пут од 1980. године, од када је у борбену употребу уведен тенк *M1 Abrams*. Од тада су спроведене веће и мање модернизације, које су се кретале од стандарда *M1,* затим *M1A1* па и *M1A2.* Тренутно се ради на програму *Engineering Change Proposal (ECP)* који ће резултирати модернизационим програмом *System Enhancement Packages (SEPs).*

Најновија верзија тенка *M1* је *M1A2 SEPv2* која ће „дигитализовати" америчку тенковску флоту. Модернизација има за циљ замену свих аналогних система дигиталним заменама, као што су унапређени дисплеји и контролни системи, али ће се односити и на помоћну погонску јединицу.

Очекује се да ће 1.600 тенкова *M1A2* бити укључено у програм *SEPv2* а у међувремену је набављено и 400 система активне заштите *Trophy-HV* од израелске компаније *Rafael Advanced Defense Systems,* па су сви системи већ и испоручени у јануару 2021. године, под ознаком хитно.

Већ се планира и следећа модернизација, под ознаком *M1A2 SEPv3,* која би укључила повећан ниво заштите, дијагностичке системе и прелазак на заменљиве модуле који би били лакши за замену. Пројект би укључио и модернизацију дигиталне структуре са гигабитном етернет мрежом, новим системом за управљање погоном и додатним генератором од 7.840 вати. Поред тога, постојаће и активна заштита против импровизованих експлозивних направа.

M1A2 SEPv2 опремљен активним системом заштите Trophy-HV

Сједињене Државе такође приводе крају планирање у вези стандарда *M1A2 SEPv4,* заснованог на предлогу *ECP1B,* на основу којег ће бити додата примарна нишанска справа командира (пре се називала независна термална осматрачка справа командира), унапређена примарна нишанска справа нишанџије, трећа генерација инфрацрвене осматрачке справе и могућност испаљивања вишенаменске тенковске гранате *XM1147* из основног топа 120 мм. Постоје информације да ће цела америчка флота тенкова *Abrams* бити доведена на ниво *SEPv3 (ECP1A),* а затим на конфигурацију *SEPv4 (ECP1B).*

У САД се активно ради на програму тенка који ће се производити од 2040. године у оквиру програма *Optionally Manned Tank.*

Француска

У Француској се, као и у Великој Британији, размишљало о куповини тенкова *Leopard 2* или *M1* пре него што је ова земља развила сопствени тенк *Leclerc*. То је најмлађи од свих НАТО тенкова, пројектован касних осамдесетих година, а ушао је у оперативну употребу 1993. године, када је заменио тенк *AMX-30*. Произведено је 308 ових тенкова у различитим стандардима, као и 20 оклопних возила за извлачење, за Француску са једним извозом за Уједињене Арапске Емирате од 388 тенкова, два тенка за обуку и 46 возила за извлачење.

Француска, као и Велика Британија, није предузела кораке ка континуираној модернизацији, као што су то радиле Немачка и САД. Уместо тога, одлучили су се за једну велику модернизацију овог тенка на

средини његовог животног века. Године 2015. компанија *Nexter* започела је модернизацију 200 тенкова и 18 возила за извлачење на стандард XLR.

Унапређење француског тенка Leclerc XLR је део програма модернизације SCORPION

Изостанак континуиране модернизације много је коштао Француску, јер модернизација на стандард *XLR* је све скупља. На пример, услед престанка производње делова турбопуњача 2014. године, ради штедње, било је потребно наћи новог добављача алтернативног система.

Након модернизације очекује се да ће француска флота тенкова остати у оперативној употреби до 2040. године, када би требало да буде замењена француско-немачким пројектом *MGCS*.

Италија

Италија је следила пут Велике Британије својим тенком *Ariete* који је први пут уведен у оперативну употребу током 1995. године. Међутим, слично као британски и француски тенкови *Challenger 2* и *Leclerc,* није континуирано модернизован, осим што је 2000. године исправљен проблем који се односио на мотор.

Године 2019. тенк улази у програм модернизације који ће омогућити његову употребу до 2030. године. Биће уведена панорамска осматрачка справа *Attila-D*, нишанска справа *LOTHAR* и систем за управљање ватром *Selex Galileo TURMS-T* који је употребљен на самоходном топу *Centauro II.* Модернизација ће обухватити електрични систем окретања куполе ради

повећања перформанси и заштите, као и нови модуларни пасивни и експлозивно-реактивни оклоп *ROMOR.*

Након краја животног века тенка *Ariete*, у Италији се размишља о уласку у заједнички развој тенка са Шпанијом, а пред крај 2020. године објављено је да би у заједнички подухват ушла и Пољска.

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Руска армија добија самоходни противтенковски топ Sprut-*SDM1 SPATG*[2]

Руско министарство одбране одлучило је да набави самоходни противтенковски топ *2S25M Sprut-SDM1,* али се још увек не зна број тих возила.

Sprut-SDM1 (Извор: Army Recognition)

Очекује се да ће 242. центар за обуку ваздушнодесантних трупа почети са обуком посада за употребу самоходног топа Sprut-SDM1 током 2021. године.

Основна варијанта самоходног противтенковског топа Sprut-SD, званично је прихваћена 2006. године. Оружни систем заснован је на борбеном возилу пешадије BMD-4, а 10 возила је испоручено војсци током 2000. године. Међутим, 2010. године обустављена је даља набавка

[2] Defense News December 2020 Global Security army industry

система поменутог система због лошег квалитета пројекта и недовољне оклопне заштите.

Ради повећања степена преживљавања, руска индустрија је развила јачу балистичку заштиту за систем *Sprut-SDM1*. Топ је потпуно интегрисан са дигиталним системом за управљање ватром, сличним оном на тенку T-90MS, што је довело до побољшања прецизности гађања и омогућило посади напад на слабо покретне и нисколетеће циљеве, као што су хеликоптери и беспилотне летелице. Самоходни противтенковски топ добио је вођену ракету *Invar-M, 9M119M1,* која се лансира кроз топовску цев. Развијена је и термобарична експлозивна бојева глава за гађање фортификацијских објеката.

Лаки тенк има борбени комплет од 40 граната за основни топ. Аутоматски пуњач носи 22 гранате, док се остатак од 18 граната налази у трупу тенка. Муниционi комплет обично садржи 20 граната *HE-FRAG*, 14 граната *APFSDS* и шест противтенковских вођених ракета. Тенковски топ има каденцу гађања од 7 граната у минути, а потрошене чауре се аутоматски избацују иза куполе.

Поред коаксијалног митраљеза калибра 7.62 мм, тенк *Sprut-SDM1* је опремљен и даљински управљаном оружном станицом са митраљезом 7.62 мм.

Амфибијски тенк *Sprut-SDM1* опремљен је независном осматрачком справом командира са термалном камером. Овај систем омогућава брже захватање и напад на циљеве. Оног тренутка када је командир тенка уочио циљ, он је прихваћен и топ се аутоматски окреће ка мети. Нишанџија завршава процес нишањења и опаљења, док командир тражи следећу мету. Овај систем назива се „ловац-убица”, а поседује га већина модерних основих борбених тенкова.

Посаду овог лаког тенка чине три члана: командир, нишанџија и возач. Командир и нишанџија налазе се у куполи.

Тенк *Sprut-SDM1* опремљен је новим вишегоривним дизел мотором *UTD-29* који развија 500 КС. Исти мотор налази се на борбеном возилу пешадије *BMP-3* и новијем *BMD-4M*. Мотор је савременији од мотора који је био уграђен у претходни тенк *Sprut-SD*. Тенк садржи велики део делова са ваздушнодесантног борбеног возила *BMD-4M.*

Амфибијски тенк има хидропнеуматско вешање са регулисањем висине. То је ваздушнодесантно , односно ваздушнопреносиво возило (траснпортни авион Il-76 може носити до два лака тенка) које се може спуштати падобранима, а наоружано је основним топом 125 мм са пуним борбеним комплетом граната. Приликом ваздушног десанта, када се тенк спушта падобранима, посада се налази у возилу. Систем је пројектован за подршку ваздушно- десантним трупама на бојишту, које су до сада имале само самоходне минобацаче *Nona-S* 120 мм са врло ограниченим противтенковским дејством.

Модернизована верзија самоходног противтенковског топа опремљена је модерним системом за управљање ватром и термалним осматрачким и

нишанским уређајем који ову платформу доводе до борбених способности основног борбеног тенка. У ствари, *Sprut-SDM1* спада у категорију лаких амфибијских тенкова. Ниједна страна земља нема лаке тенкове са амфибијским и ваздушнодесантним способностима.

Ваздушнодесантне трупе ће сада имати могућност борбе против непријатељског оклопа, а до сада су имали само борбена возила пешадије, *BMD-2,* која нису могла напасти основни борбени тенк. Ваздушно-десантне трупе су у противоклопној борби имале на располагању само два противтенковска система – ручне ракетне бацаче и противтенковске вођене ракете. Ручни ракетни бацач има ефикасни борбени домет до 400 м, док борбени комплет противтенковских вођених ракета не прелази три до четири ракете. Тенкови су много покретнији и лако могу изманеврисати стационарне батерије. Стога је било неопходно обезбедити противтенковски топ са довољним борбеним комплетом.

Амфибијска својства самоходног противтенковског топа Sprut-SDM1

Тенк *Sprut-SDM1* плови уз помоћ две водене млазнице. Максимална амфибијска брзина је до 7 км на сат. Возило може пловити по мору до тежине до трећег нивоа, а може користити и свој основни топ и гађати циљеве за време пловљења.

Самоходни противтенковски топ *Sprut-SDM1* успешно је завршио пловећи тест у региону Црног мора у децембру 2020. године. Тенк је тестиран и на високим тропским температурама, док се тестови на ниским температурама очекују током 2021. године.

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Француска је одабрала нуклеарни погон за свој будући носач авиона[3]

Француски председник Еманuел Макрон потврдио је да ће следећа генерација француског носача авиона бити на нуклеарни погон.

Нови носач авиона, под називом *Porte-Avions de Nouvelle Génération (PANG),* односно носач авиона нове генерације замениће француски носач Charles de Gaulle након 2038. године.

Француска компанија *Framatome* ради нуклеарне реакторе и пратећу опрему која ће обезбедити кључне елементе за нови реактор K22.

Компјутерски генерисана слика француског носача авиона нове генерације

Очекује се да ће нови носач авиона има носивост од око 75.000 тона, дужину до 300 м и ширину до 80 м. Нови носач авиона биће знатно већи од носача *Charles de Gaulle* чија је носивост 43.182 тоне, а дужина 260 м. Нови носач авиона имаће Посаду новог носача чиниће 2.000 људи, укључујући и пилотске посаде.

Нова генерација носача авиона имаће места за око 30 ловаца уз одређен број беспилотних летелица, авионе за рано упозорење и контролу, као и хеликоптере. Носиће и нову генерацију авиона, *Future Combat Air*

[3] Janes navy international January February 2021

System (FCAS), коју заједнички развијају Француска, Немачка и Шпанија. Максимална полетна тежина будућег авиона биће око 30 тона.

Нова генерација носача авиона биће опремљена електромагнетним катапултима. Очекује се да ће Француска опремити свој носач авиона америчким системом *Electromagnetic Aircraft Launch System (EMALS)* којим су опремљени амерички носачи авиона класе *Gerald R Ford*. Електромагнетни катапулти биће дужине 90 м (на носачу *Charles de Gaulle* они су дужине до 75 м), што ће омогућити лансирање тежих авиона. Очекује се да ће нови носач имати најмање два таква катапулта, а можда и три. Поред тога, биће опремљен и новом генерацијом заустављајућих каблова и то највероватније америчким системом *General Atomics Advanced Arresting Gear.*

Нови носач авиона имаће максималну брзину од 27 чворова, а погониће га два нуклеарна реактора типа K22 од по 220 MW који ће се пунити нуклеарним горивом сваких 10 година. Тренутно носач авиона *Charles de Gaulle* покрећу два нуклеарна реактора типа K15, снаге од по 150 MW.

Развојна фаза носача авиона трајаће до 2025. године, када ће почети његова изградња. Биће грађен у бродоградилишту *Chantier de l'Atlantique*, једином које у Француској има одговарајуће капацитете. Прве пробе очекују се током 2036, а увођење у оперативну употребу током 2038. године.

Одлука о градњи и другог носача авиона очекује се 2025. године.

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ПОЗИВ И УПУТСТВО АУТОРИМА
ПРИГЛАШЕНИЕ И ИНСТРУКЦИЯ 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 Правилника о категоризацији и рангирању научних часописа Министарства просвете, науке и технолошког развоја Републике Србије ("Службени гласник РС", број 159/20). Примена овог Правилника првенствено служи унапређењу квалитета домаћих часописа и њиховог потпунијег укључивања у међународни систем размене научних информација.

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, DOI: 10.5937/VojnotehnickiGlasnik; https://doi.org/10.5937/VojnotehnickiGlasnik), јесте мултидисциплинарни научни часопис Министарства одбране и Војске Србије. Часопис објављује научне и стручне чланке из области основних истраживања (математике, рачунарских наука и механике) и технолошког развоја (електронике, телекомуникација, информационих технологија, машинства, материјала и хемијских технологија), 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. Часопис објављује и остала теоријска и практична достигнућа која доприносе усавршавању свих припадника српске, регионалне и међународне академске заједнице, а посебно припадника војски и министарстава одбране.

Уређивачка политика Војнотехничког гласника заснива се на препорукама Одбора за етичност у издаваштву (COPE Core Practices), као и на најбољим прихваћеним праксама у научном издаваштву. Војнотехнички гласник је члан COPE (Committee on Publication Ethics) од 2. маја 2018. године.

Министарство просвете, науке и технолошког развоја Републике Србије утврдило је дана 18. 12. 2020. године категоризацију Војнотехничког гласника, за 2020. годину:

за област основна истраживања:
– на листи часописа за математику, рачунарске науке и механику:
категорија национални часопис **(М53)**,

за област технолошки развој:
– на листи часописа за електронику, телекомуникације и информационе технологије:
категорија истакнути национални часопис **(М52)**,
– на листи часописа за машинство:
категорија истакнути национални часопис **(М52)**,
– на листи часописа за материјале и хемијске технологије:
категорија истакнути национални часопис **(М52)**.

Усвојене листе домаћих часописа за 2020. годину могу се видети на сајту Војнотехничког гласника, страница *Категоризација часописа* (Министарство

просвете, науке и технолошког развоја Републике Србије још увек није објавило званичну категоризацију научних часописа за 2021. годину).

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 објединьену набавку).

Категоризација часописа извршена је према Правилнику о категоризацији и рангирању научних часописа Министарства просвете, науке и технолошког развоја Републике Србије ("Службени гласник РС", број 159/20).

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), 1,5 бод (категорија М52) и 1 бод (категорија М53).

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 (Clarivate Analytics) 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 и политика самоархивирања*.

Радови се предају путем онлајн система за електронско уређивање АСИСТЕНТ, 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 *АСИСТЕНТ* 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 АСИСТЕНТ*.

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 енглеском језику (arial, 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 и литературу (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.

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 поред имена и презимена аутора.

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 *Војнотехничком гласнику* класификују се на научне и стручне чланке.

Научни чланак је:

– оригиналан научни рад (рад у којем се износе претходно необјављени резултати сопствених истраживања научним методом);

– 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);

– кратко или претходно саопштење (оригинални научни рад пуног формата, али мањег обима или прелиминарног карактера);

– 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 чланак је:

– стручни рад (прилог у којем се нуде искуства корисна за унапређење професионалне праксе, али која нису нужно заснована на научном методу);

– информативни прилог (уводник, коментар и сл.);

– приказ (књиге, рачунарског програма, случаја, научног догађаја, и сл.).

Језик рада

Језик рада треба да буде енглески.

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

Сажетак 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 увод/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.

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. У чланку се пишу непосредно након сажетка.

Систем АСИСТЕНТ 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.

За слике и графиконе не сме се користити снимак са екрана рачунара програма за прикупљање података. У самом тексту чланка препоручује се употреба слика и графикона непосредно из програма за анализу података (као што су Excel, Matlab, Origin, SigmaPlot и други).

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 АСИСТЕНТ 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 АСИСТЕНТ у сврху контроле правилног исписа листе референци користи специјалну алатку RefFormatter: контрола обликовања референци у складу са Харвардским приручником за стил.

Изјава о ауторству

Поред чланка доставља се *Изјава о ауторству* у којој аутори наводе свој појединачни допринос у изради чланка. Такође, у тој изјави потврђују да су чланак урадили у складу са *Позивом и упутством ауторима* и *Изјавом о етичком поступању часописа*.

Сви радови подлежу стручној рецензији.

Списак рецензената Војнотехничког гласника може се видети на страници сајта *Списак рецензената*. Процес рецензирања објашњен је на страници сајта *Рецензентски поступак*.

Уредништво

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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 согласно Регламенту о категоризации и ранжировании научных журналов Министерства образования, науки и технологического развития Республики Сербия («Службени гласник РС», № 159/20). Применение этого Регламента способствует повышению качества отечественных журналов и их более полному вовлечению в международную систему обмена научной информацией.

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, DOI: 10.5937/VojnotehnickiGlasnik; https://doi.org/10.5937/VojnotehnickiGlasnik, является мультидисциплинарным научным журналом Министерства обороны и Вооруженных сил Республики Сербия.. В журнале публикуются научные и профессиональные статьи, исследующие такие области как: математика, компьютерные науки и механика, а также области технологического развития: электроника, телекоммуникации, информационные технологии, машиностроение, материалы и химические технологии, в журнале также публикуется: техническая информация о современных системах вооружения и современных военных технологиях. Журнал следит за единой межвидовой технической поддержкой вооруженных сил, основанной на принципах системной логистики, за прикладными и инновационными научными исследованиями, в том числе, в области производства вооружения и военной техники. В журнале публикуются и прочие теоретические и практические достижения, которые способствуют повышению квалификации представителей сербского, регионального и международного академического сообщества, особенно военнослужащих Министерства Обороны и Вооружённых сил.

Редакционная политика журнала «Военно-технический вестник» основана на рекомендациях Комитета по этике научных публикаций (COPE Core Practices), а также на лучшей практике в научно-издательской деятельности. «Военно-технический вестник» является членом COPE со 2 мая 2018 года.

Министерством образования, науки и технологического развития Республики Сербия утверждена 18 декабря 2020 г. категоризация журнала «Военно-технический вестник» за 2020 год:

Категории в области основных исследований:

– Область математика, компьютерные науки, технические науки:
национальный журнал **(M53)**.

Категории в области технологического развития:

– Область электроники, телекоммуникаций и информационных технологий:
высококачественный национальный журнал **(M52)**.

– Область механики:
высококачественный национальный журнал **(M52)**.

– Область материалов и химической технологии:
высококачественный национальный журнал **(M52)**.

С информацией относительно категоризации за 2020 год можно ознакомиться на странице сайта «Военно-технического вестника» *Категоризация Вестника*

(Министерством просвещения, науки и технологического развития Республики Сербия пока не произведено официального ранжирования научных журналов за 2021 год).

Более подробную информацию можно найти на сайте Министерства образования, науки и технологического развития Республики Сербия.

С информацией о категоризации можно ознакомиться и на сайте КОБСОН (Консорциум библиотек Республики Сербия по вопросам объединения закупок).

Категоризация Вестника проведена согласно Регламенту о категоризации и ранжировании научных журналов Министерства образования, науки и технологического развития Республики Сербия («Службени гласник РС», № 159/20)

В соответствии с вышеуказанным Положением и таблицей с показателями классификации и категоризации индивидуальных научно-исследовательских результатов, являющейся неотъемлемой частью Положения, научная статья, опубликованная в «Военно-техническом вестнике», оценивается следующим способом: 2 балла (категория М51), 1,5 балла (категория М52) и 1,5 балл (категория М53).

Журнал соответствует стандартам Сербского индекса научного цитирования (СЦИндекс/SCIndeks) – наукометрической базы данных научных журналов Республики Сербия, а также Российского индекса научного цитирования (РИНЦ). Журнал постоянно подвергается мониторингу и оценивается количественными наукометрическими показателями, отражающими его научную ценность, в т.ч. опосредованно в международных индексах цитирования (Clarivate Analytics).

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, утверждёнными Creative Commons (CC BY). С инструкцией об авторских правах можно ознакомиться на странице *Авторские права и политика самоархивирования*, перейдя по ссылке http://www.vtg.mod.gov.rs/index-ru.html.

Рукописи статей направляются в редакцию журнала с использованием online системы ASSISTANT, запущенной Центром поддержи развития образования и науки (ЦПРОН).

Регистрация в системе и оформление прав доступа выполняется по адресу http://www.vtg.mod.gov.rs/index-ru.html, через страницу *ASSISTANT* или *СЦИНДЕКС* (aseestant.ceon.rs/index.php/vtg).

С инструкцией по регистрации и правам доступа можно ознакомиться по адресу http://www.vtg.mod.gov.rs/index-ru.html, на странице *Инструкция по ASSISTANT*.

Все авторы, предоставляющие свои рукописи для публикации в редакцию журнала «Военно-технический вестник» должны пройти предварительную регистрацию в реестре ORCID (Open Researcher and Contributor ID). Эта процедура осуществляется в соответствии с инструкцией, размещенной на странице сайта *Регистрация в реестре ORCID для присвоения идентификационного кода*.

«Военно-технический вестник» публикует статьи на английском языке (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 резюме с ключевыми словами, введение, основную часть, выводы и список использованной литературы (без нумерации заголовков и подзаголовков). Объём статьи не должен превышать один авторский лист (16 страниц формата А4 с пробелом Single).

Статья должна быть набрана на компьютере с использованием специально подготовленного редакцией макета, который можно скачать на странице сайта *Правила и образец составления статьи*.

Заголовок

Заголовок должен отражать тему статьи. В интересах журнала и автора необходимо использовать слова и словосочетания, удобные для индексации и поиска. Если такие слова не содержатся в заголовке, то желательно их добавить в подзаголовок.

Текущий заголовок

Текущий заголовок пишется в титуле каждой страницы статьи с целью упрощения процесса идентификации, в первую очередь копий статьей в электронном виде. Заголовок содержит в себе фамилию и инициал имени автора (в случае если авторов несколько, остальные обозначаются с «et al.» или «и др.»), название работы и журнала (год, том, выпуск, начальная и заключительная страница). Заголовок статьи и название журнала могут быть приведены в сокращенном виде.

ФИО автора

Приводятся полная фамилия и полное имя (всех) авторов. Желательно, чтобы были указаны инициалы отчеств авторов. Фамилия и имя авторов из Республики Сербия всегда пишутся в оригинальном виде (с сербскими диакритическими знаками), независимо от языка, на котором написана работа.

Наименование учреждения автора (аффилиация)

Приводится полное (официальное) наименование и местонахождение учреждения, в котором работает автор, а также наименование учреждения, в котором автор провёл исследование. В случае организаций со сложной структурой приводится их иерархическая соподчинённость (напр. Военная академия, кафедра военных электронных систем, г. Белград). По крайней мере, одна из организаций в иерархии должна иметь статус юридического лица. В случае если указано несколько авторов, и если некоторые из них работают в одном учреждении, нужно отдельными обозначениями или каким-либо другим способом указать в каком из приведённых учреждений работает каждый из авторов. Аффилиация пишется непосредственно после ФИО автора. Должность и специальность по диплому не указываются.

Контактные данные

Электронный адрес автора указываются рядом с его именем 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 журнале распределяются по следующим категориям:

Научные статьи:

– оригинальная научная статья (работа, в которой приводятся ранее неопубликованные результаты собственных исследований, полученных научным методом);

– обзорная статья (работа, содержащая оригинальный, детальный и критический обзор исследуемой проблемы или области, в который автор внёс определённый вклад, видимый на основе автоцитат);

– краткое сообщение (оригинальная научная работа полного формата, но меньшего объёма или имеющая предварительный характер);

– научная критическая статья (дискуссия-полемика на определённую научную тему, основанная исключительно на научной аргументации) и научный комментарий.

Однако, в некоторых областях знаний научная работа в журнале может иметь форму монографического исследования, а также критического обсуждения научного материала (историко-архивного, лексикографического, библиографического, обзора данных и т.п.) – до сих 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 номера.

Профессиональные статьи:

– профессиональная работа (приложения, в которых предлагаются опыты, полезные для совершенствования профессиональной практики, но которые не должны в обязательном порядке быть обоснованы на научном методе);

– информативное приложение (передовая статья, комментарий и т.п.);

– обзор (книги, компьютерной программы, случая, научного события и т.п.).

Язык работы

Статья должна быть написана на английском языке.

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, проставляемыми с правой стороны в круглых скобках.

Резюме

Резюме является кратким информативным обзором содержания статьи, обеспечивающим читателю быстроту и точность оценки её релевантности. В интересах редакции и авторов, чтобы резюме содержало термины, часто используемые для индексирования и поиска статьей. Составными частями резюме являются введение/цель исследования, методы, результаты и выводы. В резюме должно быть от 100 до 250 слов, и оно должно находится между титулами (заголовок, ФИО авторов и др.) и ключевыми словами, за которыми следует текст статьи.

Ключевые слова

Ключевыми словами являются термины или фразы, адекватно представляющие содержание статьи, необходимые для индексирования и поиска. Ключевые слова необходимо выбирать, опираясь при этом на какой-либо международный источник (регистр, словарь, тезаурус), наиболее используемый внутри данной научной области. Число ключевых слов не может превышать 10. В интересах редакции и авторов, чтобы частота их встречи в статье была как можно большей. В статье они пишутся непосредственно после резюме.

Программа ASSISTANT предоставляет возможность использования сервиса KWASS, автоматически фиксирующего ключевые слова из источников/словарей по выбору автора/редактора.

Дата получения статьи

Дата, когда редакция получила статью; дата, когда редакция окончательно приняла статью к публикации; а также дата, когда были предоставлены необходимые исправления рукописи, приводятся в хронологическом порядке, как правило, в конце статьи.

Выражение благодарности

Наименование и номер проекта, т.е. название программы благодаря которой статья возникла, совместно с наименованием учреждения, которое финансировало проект или программу, приводятся в отдельном примечании, как правило, внизу первой страницы статьи.

Предыдущие версии работы

В случае если статья в предыдущей версии была изложена устно (под одинаковым или похожим названием, например, в виде доклада на научной конференции), сведения об этом должны быть указаны в отдельном примечании, как правило, внизу первой страницы статьи. Работа, которая уже была опубликована в каком-либо из журналов, не может быть напечатана в «Военно-техническом вестнике» ни под похожим названием, ни в изменённом виде.

Нумерация и название таблиц и графиков

Желательно, чтобы нумерация и название таблиц и графиков были исполнены на двух языках (на языке оригинала и на английском). Таблицы подписываются таким же способом как и текст и обозначаются порядковым номером с верхней стороны. Фотографии и рисунки должны быть понятны, наглядны и удобны для репродукции. Рисунки необходимо делать в программах Word или Corel. Фотографии и рисунки надо поставить на желаемое место в тексте. Для создания изображений и графиков использование функции снимка с экрана (скриншота) не допускается. В самом тексте статьи рекомендуется применение изображений и графиков, обработанных такими компьютерными программами, как: Excel, Matlab, Origin, SigmaPlot и др.

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 применяет Гарвардскую систему (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: (Petrović, 2010, pp.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 ASSISTANT предоставляет при цитировании возможность использования сервиса CiteMatcher, фиксирующего пропущенные цитаты в работе и в списке литературы.

Примечания (сноски)

Примечания (сноски) к тексту указываются внизу страницы, к которой они относятся. Примечания могут содержать менее важные детали, дополнительные объяснения, указания об использованных источниках (напр. научном материале, справочниках), но не могут быть заменой процедуры цитирования литературы.

Литература (референции)

Цитированной литературой охватываются, как правило, такие библиографические источники как статьи, монографии и т.п. Вся используемая литература в виде референций размещается в отдельном разделе статьи.

Названия литературных источников не переводятся на язык работы.

«Военно-технический вестник» для оформления списка использованной литературы применяет Гарвардскую систему (Harvard Style Manual). В списке литературы источники указываются в алфавитном порядке фамилий 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.

При оформлении списка литературы программа ASSISTANT предоставляет возможность использования сервиса RefFormatter, осуществляющего 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.

Авторское заявление

Авторское заявление предоставляется вместе со статьей, в нем авторы заявляют о своем личном вкладе в написание статьи. В заявлении авторы подтверждают, что статья написана в соответствии с *Приглашением и инструкциями для авторов*, а также с *Кодексом профессиональной этики журнала*.

Все рукописи статей подлежат профессиональному рецензированию.

Список рецензентов журнала «Военно-технический вестник» размещён на странице сайта *Список рецензентов*. Процесс рецензирования описан в разделе *Правила рецензирования*.

Редакция

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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 Regulations on categorization and ranking of scientific journals of the Ministry of Education, Science and Technological Development of the Republic of Serbia (Official Gazette of the Republic of Serbia, No 159/20). This Regulations aims at improving the quality of national journals and raising the level of their compliance with the international system of scientific information exchange.

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, DOI: 10.5937/VojnotehnickiGlasnik; https://doi.org/10.5937/VojnotehnickiGlasnik) is a multidisciplinary scientific journal of the Ministry of Defence and the Serbian Armed Forces. The journal publishes scientific and professional papers covering fundamental research (mathematics, computer science and mechanics) and technological development (electronics, telecommunications, information technologies, mechanical engineering, material science and chemical technologies) as well as technical data on modern weapon systems and military technologies. The journal covers inter-service technical support to the Army on the principle of logistic system support; fundamental, applied and development research; production and use of weapons and military equipment. Also, the journal publishes other theoretical and practical achievements leading to professional development of all members of Serbian, regional and international academic communities as well as members of the military and ministries of defence in particular.

The editorial policy of the Military Technical Courier is based on the COPE Core Practices and the journal articles are consistent with accepted best practices in their subject areas. As of 2 May 2018, the Military Technical Courier is a member of COPE (Committee on Publication Ethics).

The Ministry of Education, Science and Technological Development of the Republic of Serbia classified the Military Technical Courier for the year 2020, on December 18, 2020

in the field fundamental research:
– on the list of periodicals for mathematics, computer sciences and mechanics,
category: national journal **(M53)**,
in the field technological development:
– on the list of periodicals for electronics, telecommunications and IT,
category: quality national journal **(M52)**,
– on the list of periodicals for mechanical engineering,
category: quality national journal **(M52)**,
– on the list of periodicals for materials and chemical technology,
category: quality national journal **(M52)**.

The approved lists of national periodicals for the year 2020 can be viewed on the website of the Military Technical Courier, page *Journal categorization* (The Ministry of Education, Science and Technological Development of the Republic of Serbia has not yet published the official evaluation of scientific journals for 2021).

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 categorization and ranking of scientific journals of the Ministry of Education, Science and Technological Development of the Republic of Serbia (Official Gazette of the Republic of Serbia, No 159/20). 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), 1,5 (one and a half) point (category M52) and 1 (one) point (category M53).

The journal is in the Serbian Citation Index – SCIndex (data base of national scientific journals), in the Russian Index of Science Citation/Российский индекс научного цитирования (RINC/РИНЦ) and is constantly monitored depending on the impact within the bases themselves and indirectly in the international (e.g. Clarivate Analytics) citation indexes. More detailed information can be viewed on the website of the Military Technical Courier, page *Journal indexing*.

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