ISSN 0042-8469
e-ISSN 2217-4753
УДК 623 + 355/359

Вол. 71, бр. 3
2023

НАУЧНИ ЧАСОПИС МИНИСТАРСТВА ОДБРАНЕ И ВОЈСКЕ СРБИЈЕ

ВОЈНОТЕХНИЧКИ ГЛАСНИК

ВОЈНОТЕХНИЧКИ ГЛАСНИК 2023 3

втг.мо.упр.срб
www.vtg.mod.gov.rs

ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК 2023 3

ISSN 0042-8469
e-ISSN 2217-4753
УДК 623 + 355/359

Том 71, № 3

2023

НАУЧНЫЙ ЖУРНАЛ МИНИСТЕРСТВА ОБОРОНЫ
И ВООРУЖЕННЫХ СИЛ РЕСПУБЛИКИ СЕРБИЯ

ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК

втг.мо.упр.срб

www.vtg.mod.gov.rs

MILITARY TECHNICAL COURIER 2023 3

Vol. 71, Issue 3

2023

ISSN 0042-8469
e-ISSN 2217-4753
UDC 623 + 355/359

MTC

SCIENTIFIC JOURNAL OF THE MINISTRY OF DEFENCE AND THE SERBIAN ARMED FORCES

MILITARY TECHNICAL COURIER

втг.мо.упр.срб

www.vtg.mod.gov.rs

ISSN 0042-8469
e-ISSN 2217-4753
UDC 623 + 355/359

НАУЧНИ ЧАСОПИС МИНИСТАРСТВА ОДБРАНЕ И ВОЈСКЕ СРБИЈЕ

ВОЈНОТЕХНИЧКИ ГЛАСНИК

ВОЛУМЕН 71 • БРОЈ 3 • ЈУЛ – СЕПТЕМБАР 2023.

NAUČNI ČASOPIS MINISTARSTVA ODBRANE I VOJSKE SRBIJE

VOJNOTEHNIČKI GLASNIK

VOLUMEN 71 • BROJ 3 • JUL – SEPTEMBAR 2023.

втг.мо.упр.срб
www.vtg.mod.gov.rs
COBISS.SR-ID 4423938
DOI: 10.5937/VojnotehnickiGlasnik

ISSN 0042-8469
e-ISSN 2217-4753
UDC 623 + 355/359

НАУЧНЫЙ ЖУРНАЛ МИНИСТЕРСТВА ОБОРОНЫ И ВООРУЖЁННЫХ СИЛ РЕСПУБЛИКИ СЕРБИЯ

ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК

ТОМ 71 • НОМЕР ВЫПУСКА 3 • ИЮЛЬ – СЕНТЯБРЬ 2023.

SCIENTIFIC JOURNAL OF THE MINISTRY OF DEFENCE AND SERBIAN ARMED FORCES

MILITARY TECHNICAL COURIER

VOLUME 71 • ISSUE 3 • JULY – SEPTEMBER 2023

втг.мо.упр.срб
www.vtg.mod.gov.rs
COBISS.SR-ID 4423938
DOI: 10.5937/VojnotehnickiGlasnik

ВЛАСНИЦИ:
Министарство одбране и Војска Србије

ИЗДАВАЧ:
Универзитет одбране у Београду, Војна академија

СОБСТВЕННИКИ: Министерство обороны и Вооружённые силы Республики Сербия

ИЗДАТЕЛЬСТВО: Университет обороны в г. Белград, Военная академия

OWNERS:
Ministry of Defence and Serbian Armed Forces

PUBLISHER:
University of Defence in Belgrade, Military Academy

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

ОРИГИНАЛНИ НАУЧНИ РАДОВИ
ОРИГИНАЛЬНЫЕ НАУЧНЫЕ СТАТЬИ
ORIGINAL SCIENTIFIC PAPERS

Note on the temperature Sombor index

Ivan Gutman

University of Kragujevac, Faculty of Science,
Kragujevac, Republic of Serbia,
e-mail: gutman@kg.ac.rs,
ORCID iD: https://orcid.org/0000-0001-9681-1550

DOI: 10.5937/vojtehg71-44132; https://doi.org/10.5937/vojtehg71-44132

FIELD: mathematics (mathematics subject classification: primary 05c07, secondary 05c09)
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The temperature of a vertex of a graph of the order n is defined as d/(n-d), where d is the vertex degree. The temperature variant of the Sombor index is investigated and several of its properties established.

Methods: Combinatorial graph theory is applied.

Results: Extremal values and bounds for the temperature Sombor index are obtained.

Conclusion: The paper contributes to the theory of Sombor-index-like graph invariants.

Keywords: temperature (of vertex), temperature vertex-degree-based graph invariant, Sombor index, temperature Sombor index.

Introduction

In this paper, we examine a class of vertex-degree-based (VDB) graph invariants. Let *G* be a simple graph with *n* vertices and *m* edges. Let *V*(*G*) and *E*(*G*) be its vertex and edge sets, respectively. Then $|V(G)|=n$ and $|E(G)|=m$. The edge of the graph *G*, connecting the vertices *u* and *v*, will be denoted by *uv*. The degree d_u of the vertex *u* is the number of its first neighbors.

The graph in which any two vertices are adjacent is said to be complete and is denoted by K_n. It has *m=n(n-1)/2* edges. Its complement, denoted by $\overline{K}_n$, is the edgeless graph, with *m*=0.

For additional details of graph theory, see (Harary, 1969; Bondy & Murty, 1976).

In the recent mathematical and chemical literature, a large number of graph invariants of the form

$$TI = TI(G) = \sum_{uv \in E(G)} f(d_u, d_v) \quad (1)$$

are studied, where *f* is a pertinently chosen function with the property *f(x,y)=f(y,x)*; for details, see (Gutman, 2023) and the references cited therein. The quantities defined via Eq. (1) are usually referred to as vertex-degree-based (VDB) graph invariants. Of these, one of the oldest is the first Zagreb index (Gutman & Trinajstić, 1972; Gutman & Das, 2004):

$$M_1 = M_1(G) = \sum_{uv \in E(G)} (d_u + d_v)$$

whereas one of the most recent ones is the Sombor index (Gutman, 2021; Liu et al, 2022):

$$SO = SO(G) = \sum_{uv \in E(G)} \sqrt{d_u^{\,2} + d_v^{\,2}}\ .$$

According to Fajtlowicz (Fajtlowicz, 1988), the temperature of the vertex u of a graph with n vertices is defined as

$$t_u = \frac{d_u}{n - d_u} \quad (2)$$

where one should recall that in the case of *n*-vertex graphs, $0 \le d_u \le n-1$.

Directly from this definition, it follows that

$$\frac{2m}{n} \le \sum_{u \in V(G)} t_u \le 2m\ .$$

The equality on the left-hand side holds if $G \cong \overline{K}_n$, whereas the right-hand side equality holds if either $G \cong K_n$ or $G \cong \overline{K}_n$.

In Eq. (1), by replacing the vertex degrees with vertex temperatures, one obtains the respective temperature VDB graph invatiants, namely:

$$TTI = TTI(G) = \sum_{uv \in E(G)} f(t_u, t_v) \, .$$

Such are the temperature first Zagreb index

$$TM_1 = TM_1(G) = \sum_{uv \in E(G)} (t_u + t_v) \qquad (3)$$

and the temperature Sombor index

$$TSO = TSO(G) = \sum_{uv \in E(G)} \sqrt{t_u^{\,2} + t_v^{\,2}} \, .$$

Several other temperature VDB graph invariants were studied in the literature (Narayankar et al, 2018; Kahsay et al, 2018; Kulli, 2019a; Kulli, 2019b; Kulli, 2021).

The temperature Sombor index was first considered by Kulli (Kulli, 2022). In this paper, we establish a few more of its properties.

Preparation: temperature first Zagreb index

Bearing in mind that for all vertices of any *n*-vertex graph, $d_u \leq n-1$, directly from Eq. (2), we obtain:

$$t_u = \frac{\dfrac{d_u}{n}}{1 - \dfrac{d_u}{n}} = \sum_{k=1}^{\infty} \left(\frac{d_u}{n} \right)^k .$$

Substituting this into Eq. (3) yields

$$\frac{1}{n^3} TM_1 = \sum_{uv \in E(G)} \sum_{k=1}^{\infty} \frac{1}{n^{k+3}} \left(d_u^{\,k} + d_v^{\,k} \right) = \sum_{k=1}^{\infty} \left(\frac{1}{n^{k+3}} \sum_{u \in V(G)} d_u^{\,k+1} \right) \qquad (4)$$

where we used the identity (Gutman, 2015)

$$\sum_{uv \in E(G)} [g(u) + g(v)] = \sum_{u \in V(G)} d_u \, g(u)$$

which holds for any quantity *g* determined by the vertex *u*. Note that TM_1 had to be be divided by n^3 because the maximum possible value of $\sum_{u \in V(G)} d_u^{\,k+1}$ is $n(n-1)^{k+1} \approx n^{k+2}$.

In connection with formula (4), one should note that for *k*=1 and *k*=2, the term $\sum_{u\in V(G)} d_u^{\,k+1}$ is equal to the well-known and much studied VDB invariants – the first Zagreb index M_1 and the so-called forgotten index *F* (Furtula & Gutman, 2015), respectively. The same term for k=3 and k=4 coincides with the VBD invariants *Y* and *S*, recently introduced in (Alameri et al, 2020) and (Nagarajan et al, 2021), respectively.

Therefore, $TM_1 \approx \frac{1}{n} M_1 + \frac{1}{n^2} F$, which is an approximation that would satisfy all practical applications of the temperature first Zagreb index. A somewhat better, yet more perplexed approximation would be $TM_1 \approx \frac{1}{n} M_1 + \frac{1}{n^2} F + \frac{1}{n^3} Y + \frac{1}{n^4} S$.

On the temperature Sombor index

It is evident from Eq. (2) that the temperature of a vertex is a monotonously increasing function of the respective vertex degree. Therefore, by deleting an adge $e \in E(G)$ from the graph *G*, some of its vertex temperatures must decrease, and no vertex temperature will increase. This implies,

$$TSO(G-e) < TSO(G). \tag{5}$$

From relation (5), we immediately conclude the following:

(1) The complete graph and its complement have the maximum and minimum temperature Sombor indices, i.e.,

$$0 = TSO(\bar{K}_n) \le TSO(G) \le TSO(K_n) = \frac{1}{\sqrt{2}} n(n-1)^2 .$$

(2) The connected graph with the minimum value of *TSO* must be a tree.

(3) Based on a general result for VDB graph invariants (Cruz & Rada, 2019), the trees with the maximum and minimum temperature Sombor indices are the star and the path, respectively.

In what follows, we use the well-known inequality

$$\frac{1}{\sqrt{2}}(a+b) \le \sqrt{a^2+b^2} \le a+b$$

valid for $a,b \ge 0$, with the left-hand side equality if *a*=*b*, and the right-hand side inequality in the irrelevant case *a*=*b*=0. Applying it to *TSO,* we get

$$\frac{1}{\sqrt{2}} \sum_{uv \in E(G)} (t_u + t_v) \le TSO(G) < \sum_{uv \in E(G)} (t_u + t_v)$$

i.e.,

$$\frac{1}{\sqrt{2}} TM_1(G) \le TSO(G) < TM_1(G)$$

With the left-hand side equality if and only if the graph *G* is regular, i.e., if all its vertices have mutually equal degrees.

Bearing in mind Eq. (4), we get

$$\frac{1}{\sqrt{2}} \sum_{k=1}^{\infty} \left(\frac{1}{n^{k+3}} \sum_{u \in V(G)} d_u^{\,k+1} \right) \le \frac{1}{n^3} TSO(G) < \sum_{k=1}^{\infty} \left(\frac{1}{n^{k+3}} \sum_{u \in V(G)} d_u^{\,k+1} \right). \quad (6)$$

From (6), we immediately obtain the following lower bounds for *TSO*.

$$TSO(G) \ge \frac{1}{\sqrt{2}} \left(\frac{1}{n} M_1(G) + \frac{1}{n^2} F(G) \right) \quad (7)$$

or, better, but more complicated,

$$TSO(G) \ge \frac{1}{\sqrt{2}} \left(\frac{1}{n} M_1(G) + \frac{1}{n^2} F(G) + \frac{1}{n^3} Y(G) + \frac{1}{n^4} S(G) \right). \quad (8)$$

The equality in (7) and (8) holds if $G \cong \overline{K}_n$.

In order to get an upper bound for *TSO,* we modify the right-hand side of (6) as

$$TSO(G) < \frac{1}{n} M_1(G) + \frac{1}{n^2} F(G) + \sum_{k=3}^{\infty} \frac{1}{n^k} (n-1)^{k+1}$$

from which it follows

$$TSO(G) < \frac{1}{n} M_1(G) + \frac{1}{n^2} F(G) + (n-1)^2 \left(1 - \frac{1}{n} - \frac{n-1}{n^2} \right).$$

References

Alameri, A., Al-Naggar, N., Al-Rumaima, M. & Alsharafi, M. 2020. Y-index of some graph operations. *International Journal of Applied. Engineering Research*, 15(2), pp.173-179 [online]. Available at: https://www.ripublication.com/ijaer20/ijaerv15n2_11.pdf [Accessed: 19 April 2023].

Bondy, J.A. & Murty, U.S.R. 1976. *Graph Theory with Applications*. New York: Macmillan Press. ISBN: 0-444-19451-7.

Cruz, R. & Rada, J. 2019. The path and the star as extremal values of vertex-degree-based topological indices among trees. *MATCH Communications in Mathematical and in Computer Chemistry,* 82, pp.715-732 [online]. Available at: https://match.pmf.kg.ac.rs/electronic_versions/Match82/n3/match82n3_715-732.pdf [Accessed: 19 April 2023].

Fajtlowicz, S. 1988. On Conjectures of Graffitti. *Annals of Discrete Mathematics*, 38, pp.113-118. Available at: https://doi.org/10.1016/S0167-5060(08)70776-3.

Furtula, B. & Gutman, I. 2015. A forgotten topological index. *Journal of Mathematical Chemistry*, 53, pp.1184-1190. Available at: https://doi.org/10.1007/s10910-015-0480-z.

Gutman, I. 2015. Edge-decomposition of Topological Indices. *Iranian Journal of Mathematical Chemistry*, 6(2), pp.103-108. Available at: https://doi.org/10.22052/IJMC.2015.10107.

Gutman, I. 2021. Geometric Approach to Degree–Based Topological Indices: Sombor Indices. *MATCH Communications in Mathematical and in Computer Chemistry*, 86, pp.11-16 [online]. Available at: https://match.pmf.kg.ac.rs/electronic_versions/Match86/n1/match86n1_11-16.pdf [Accessed: 19 April 2023].

Gutman, I. 2023. On the spectral radius of VDB graph matrices. *Vojnotehnički glasnik/Military Technical Courier,* 71(1), pp.1-8. Available at: https://doi.org/10.5937/vojtehg71-41411.

Gutman, I. & Das, K.C. 2004. The first Zagreb index 30 years after. *MATCH Communications in Mathematical and in Computer Chemistry*, 50, pp.83-92 [online]. Available at: https://match.pmf.kg.ac.rs/electronic_versions/Match50/match50_83-92.pdf [Accessed: 19 April 2023].

Gutman, I. & Trinajstić, N. 1972. Graph theory and molecular orbitals. Total φ-electron energy of alternant hydrocarbons. *Chemical Physics Letters*, 17(4), pp.535-538. Available at: https://doi.org/10.1016/0009-2614(72)85099-1.

Harary, F. 1969. *Graph Theory*. Boca Raton: CRC Press. Available at: https://doi.org/10.1201/9780429493768. ISBN: 9780429493768.

Kahsay, A.T., Narayankar, K. & Selvan, D. 2018. Atom bond connectivity temperature index of certain nanostructures. *Journal of Discrete Mathematics and Its Applications,* 8(2) pp.67-75. Available at: https://doi.org/10.22061/JMNS.2018.3624.1032.

Kulli, V.R. 2019a. Some Multiplicative Temperature Indices of HC_5C_7 [p, q] Nanotubes. *International Journal of Fuzzy Mathematical Archive*, 17(2), pp.91-98. Available at: https://doi.org/10.22457/206ijfma.v17n2a4.

Kulli, V.R. 2019b. The (a,b)-Temperature Index of *H*-Naphtalenic Nanotubes. *Annals of Pure and Applied Mathematics*, 20(2) pp.85-90. Available at: https://doi.org/10.22457/apam.643v20n2a7.

Kulli, V.R. 2021. The (a,b)-KA temperature indices of tetrameric 1,3-adamantane. *International Journal of Recent Scientific Research,* 12(2), pp.40929-40933 [online]. Available at: https://recentscientific.com/sites/default/files/17380-A-2021_0.pdf [Accessed: 19 April 2023].

Kulli, V.R. 2022. Temperature-Sombor and temperature-nirmala indices. *International Journal of Mathematics and Computer Research (IJMCR),* 10(9), pp.2910-2915. Available at: https://doi.org/10.47191/ijmcr/v10i9.04.

Liu, H., Gutman, I., You, L. & Huang, Y. 2022. Sombor index: review of extremal results and bounds. *Journal of Mathematical Chemistry*, 60, pp.771-798. Available at: https://doi.org/10.1007/s10910-022-01333-y.

Nagarajan, S., Kayalvizhi, G. & Priyadharsini, G. 2021. S-Index of Different Graph Operations. *Asian Research Journal of Mathematics*, 17(12), pp.43-52, Available at: https://doi.org/10.9734/arjom/2021/v17i1230347.

Narayankar, K.P., Kahsay, A.T. & Selvan, D. 2018. Harmonic temperature index of certain nanostructures. *International Journal of Mathematics Trends and Technology (IJMTT)*, 56(3), pp.159-164.

Заметка о температурном индексе города Сомбор

Иван Гутман

Крагуевацкий университет, естественно-математический факультет, г. Крагуевац, Республика Сербия

РУБРИКА ГРНТИ: 27.29.19 Краевые задачи и задачи на собственные значения для обыкновенных дифференциальных уравнений и систем уравнений
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Температура вершины графа порядка n определяется как d/(n-d), в котором d представляет степень вершины. Исследован температурный вариант индекса Сомбора и доказаны некоторые его свойства.

Методы: В данной статье применяется комбинаторная теория графов.

Результаты: В результате исследования были получены предельные значения температурного индекса Сомбора и его верхние и нижние пределы.

Выводы: Данное исследования вносит вклад в теорию инвариантов графов сомборского типа.

Ключевые слова: температура (вершины), температурный инвариант графа, основанный на степени вершины, индекс Сомбора, температурный индекс Сомбора.

Белешка о температурском сомборском индексу

Иван Гутман

Универзитет у Крагујевцу, Природно-математички факултет, Крагујевац, Република Србија

ОБЛАСТ: математика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Температура чвора у графу реда n дефинисана је као d/(n-d), где је d степен чвора. Истраживана је температурска варијанта сомборског индекса и доказане су неке њене особине.

Методе: Примењена је комбинаторна теорија графова.

Резултати: Одређене су екстремне вредности за температурски сомборски индекс, и нађене доње и горне границе.

Закључак: Рад доприности теорији графовских инваријанти сомборског типа.

Кључне речи: температура (чвора), графовска инваријанта зависна од степена чворова, сомборски индекс, температурски сомборски индекс.

EDITORIAL NOTE: The author of this article, Ivan Gutman, is a current member of the Editorial Board of the *Military Technical Courier*. Therefore, the Editorial Team has ensured that the double blind reviewing process was even more transparent and more rigorous. The Team made additional effort to maintain the integrity of the review and to minimize any bias by having another associate editor handle the review procedure independently of the editor – author in a completely transparent process. The Editorial Team has taken special care that the referee did not recognize the author's identity, thus avoiding the conflict of interest.

КОММЕНТАРИЙ РЕДКОЛЛЕГИИ: Автор данной статьи Иван Гутман является действующим членом редколлегии журнала «Военно-технический вестник». Поэтому редколлегия провела более открытое и более строгое двойное слепое рецензирование. Редколлегия приложила дополнительные усилия для того чтобы сохранить целостность рецензирования и свести к минимуму предвзятость, вследствие чего второй редактор-сотрудник управлял процессом рецензирования независимо от редактора-автора, таким образом процесс рецензирования был абсолютно прозрачным. Редколлегия во избежание конфликта интересов позаботилась о том, чтобы рецензент не узнал кто является автором статьи.

РЕДАКЦИЈСКИ КОМЕНТАР: Аутор овог чланка Иван Гутман је актуелни члан Уређивачког одбора *Војнотехничког гласника*. Због тога је уредништво спровело транспарентнији и ригорознији двострукослепи процес рецензије. Уложило је додатни напор да одржи интегритет рецензије и необјективност сведе на најмању могућу меру тако што је други уредник сарадник водио процедуру рецензије независно од уредника аутора, при чему је тај процес био апсолутно транспарентан. Уредништво је посебно водило рачуна да рецензент не препозна ко је написао рад и да не дође до конфликта интереса.

Paper received on / Дата получения работы / Датум пријема чланка: 23.04.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 22.05.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 24.05.2023.

Portfolio investment based on probabilistic multi-objective optimization and uniform design for experiments with mixtures

Maosheng Zheng[a], *Jie* Yu[b]

[a] Northwest University, School of Chemical Engineering,
Xi'an, People's Republic of China,
e-mail: mszhengok@aliyun.com, **corresponding author**,
ORCID iD: https://orcid.org/0000-0003-3361-4060

[b] Northwest University, School of Life Science,
Xi'an, People's Republic of China,
e-mail: yujie@nwu.edu.cn,
ORCID iD: https://orcid.org/0000-0001-6606-5462

DOI: 10.5937/vojtehg71-41828; https://doi.org/10.5937/vojtehg71-41828

FIELD: mathematics, operation research, security
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: In this paper, a new approach to solving the portfolio investment problem is formulated to handle simultaneous optimization of both maximizing the rate of return and minimizing the variance of the rate of return. Probability - based multi – objective optimization is combined with uniform design for experiments with mixtures to conduct processing.

Methods: Preliminarily, probability - based multi – objective optimization is employed to synthesize the bi-objective problem of simultaneous optimization of both maximizing the rate of return and minimizing the variance of the rate of return into a single objective one of the total preferable probability of each alternative scenario. The total preferable probability is the product of all partial preferable probabilities of each performance utility; subsequently, the method of uniform design for experiments with mixtures is used to create a set of effective sampling points for the portfolio investment problem to provide discretization in data processing and simplifying treatment, of which the proportion x_i follows the constraint condition of $x_1 + x_2 + x_3 . . . + x_s = 1$ with the total number of variables s for x_i.

Results: The new approach is used to deal with the portfolio Investment problem that is, in essence, simultaneous optimization of both maximizing the rate of return and minimizing the variance of the rate of return, which leads to reasonable consequences. The results are with the quality of rationality from the respect of the probability theory for simultaneous optimization of multiple objectives.

Conclusion: This method naturally reflects the essence of the portfolio investment problem and opens a new way of solving the relevant problem.

Key words: portfolio investment problem, multi-objective optimization, preferable probability, discrete sampling, probability theory.

Introduction

Portfolio investment aims to diversify investment risks in an effective way. Markowitz proposed a decision - making model of portfolio investment in 1952 which is seen as the foundation of the modern portfolio theory (Wang, 2022).

In Markowitz's treatment, the expected rate of return and the variance of the rate of return are employed to evaluate risky securities, with the latter used to reflect risk. The significant consequence of Markowitz's investigation is that investors should invest their funds in several securities instead in only one, so that investment risk could be reduced and appropriate investment returns obtained.

However, Markowitz's algorithm could only deal either with maximizing the expected rate of return and setting the variance of the rate of return as a restraint condition or with minimizing the variance of the rate of return and letting the expected rate of return be a constraint condition once at a time. In other words, such an approach could not handle simultaneous optimization of both maximizing the rate of return and minimizing the variance of the rate of return rationally due to the lack of appropriate methodology for dealing with multi-objective optimization (Sarmas et al, 2020; Oberoi et al, 2020; Nisani & Shelef, 2021).

Recently, Zheng et al (2022a) proposed probability - based multi – objective optimization in viewpoint of system theory, which created a brand new concept of "preferable probability"; furthermore, assessments for probability – based multi – objective optimization were put forward from the respects of the probability theory and the set theory. As a rationally novel approach concerning multiple objectives, it could be used in many fields, including energy planning, programming problems, operation research, financial affairs, management programs, material selection, mechanical design, engineering design, etc.

In this article, probability - based multi – objective optimization is combined with uniform design for experiments with mixtures to deal with the portfolio problem, so as to deal with the problem of simultaneous optimization of both maximizing the rate of return and minimizing the variance of the rate of return rationally.

Solution of the portfolio problem in the light of probability - based multi - objective optimization methodology and uniform design for experiments with mixtures

In this section, probability - based multi - objective optimization and uniform design for experiments with mixtures are organically combined, which establishes a rational method for solving the portfolio investment problem of simultaneous optimization of both maximizing the rate of return and minimizing the variance of the rate of return, i.e, a bi-objective problem. The probability - based multi - objective optimization method is used to transfer a bi - objective optimization problem into a single - objective optimization problem from the perspective of the probability theory naturally; the discretization of uniform design for experiments with mixtures provides an effective discrete sampling to simplify mathematical processing.

The systematic implementation is demonstrated by sub – sections A), B), and C).

A) Fundamental spirit of probabilistic multi - objective optimization

In the spirit of probability - based multi - objective optimization, each objective can be analogically represented as a single event in a system (Zheng et al, 2022a) and the whole event of multi - objective simultaneous optimization corresponds to the product of all single objectives (events). All performance utility indexes of a candidate are preliminarily classified into two types: i.e., beneficial type and unbeneficial type, in accordance with the role and preference of a candidate in the optimization, respectively. Specifically, the assessment of the preferable probability P_{ij} of both beneficial indicators and unbeneficial indicators can be carried out according to the evaluation procedure in Fig. 1 (Zheng et al, 2022a).

The meanings of the quantities and the factors in Fig. 1 are as follows:

P_{ij} indicates the partial preferable probability of the *j*-th performance utility indicator of the *i*-th alternative scenario, X_{ij}; *n* expresses the total number of the alternative scenario; *m* reflects the total number of the performance (objective); $\overline{X_j}$ represents the arithmetic value of the *j*-th performance utility indicator; X_{jmax} and X_{jmin} show the maximum and minimum values of the *j*-th performance utility indicator, respectively; α_j

and β_j express the normalized factors of the j-th performance utility indicator X_{ij} in the beneficial status and in the unbeneficial status, individually; the beneficial status or the unbeneficial status of the j-th performance utility indicator X_{ij} is determined according to its specific role or preference in the instant problem; and P_i represents the total (overall) preferable probability of the i-th alternative scenario (Zheng et al, 2022a).

Here, as to the portfolio investment problem, a simultaneous maximization of the rate of return and minimization of the variance of the rate of return is a typical bi-objective problem which contains a beneficial indicator and an unbeneficial indicator, respectively.

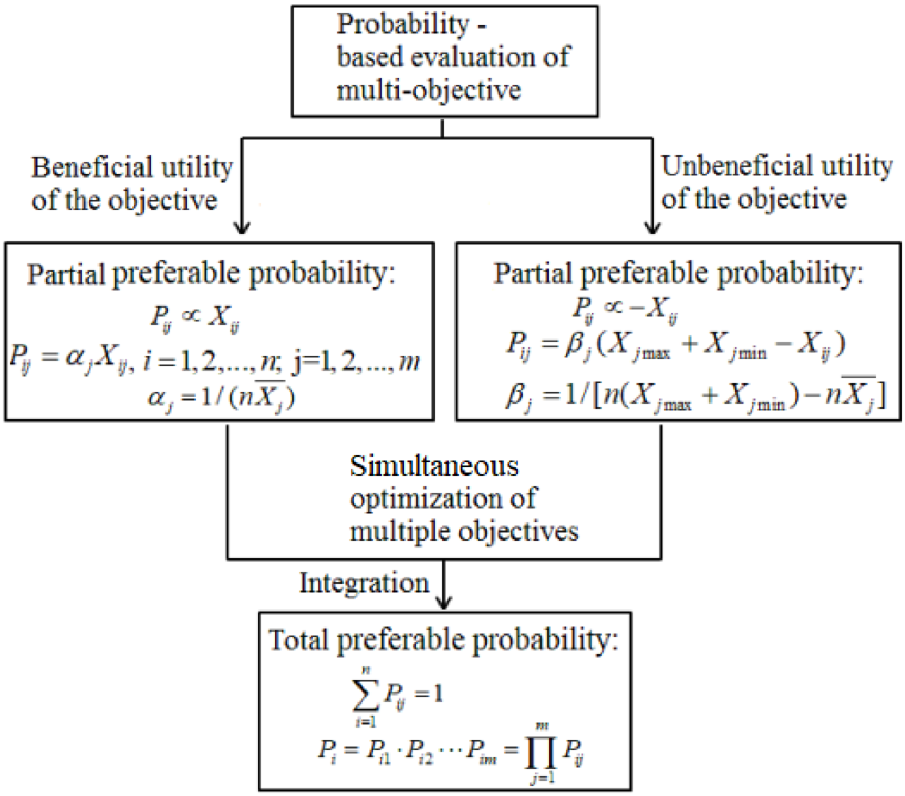


Figure 1 – Evaluation procedure of the PMOO method
Рис. 1 – Процедура оценки метода многокритериальной оптимизации, основанной на вероятности
Слика 1 – Поступак евалуације метода вишекритеријумске оптимизације засноване на вероватноћи

B) Discrete sampling in the spirit of uniform design for experiments with mixtures

In this bi - objective portfolio investment problem, the total preferable probability is the decisive objective function which needs to be maximized in a high-dimensional space, so the complex data treatment might be involved; thus uniform design for experiments with mixtures (UDEM) can be employed to simplify data processing rationally.

Uniform design for experiments with mixtures (UDEM), based on the good lattice point (GLP), was proposed by Fang et al (2018). The method of UDEM can be used to create a set of effective sampling points for experimental design with the restraint of $x_l + x_2 + x_3 . \ . \ . + x_s = 1$ for the proportion x_i with the total number of s (Fang et al, 2018); therefore, it can be used as an efficient sampling method for the portfolio investment problem here to conduct the simplification of data processing with discretization.

In addition, Fang especially developed uniform design tables and their usage tables for proper application (Fang et al, 2018).

According to Fang et al (2018), the concrete steps of uniform design for experiments with mixtures (UDEM) are generally as follows:

I. Selection of the uniform design table

Given the number of mixtures s and the number of sampling points n, select the corresponding table $U^*_n(n^t)$ or $U_n(n^t)$ and the usage table from the uniform design table provided by Fang et al (2018), and the number of columns of the usage table is selected as $s\text{-}1$ at this time. Give a mark of the original elements in the uniform design table $U^*_n(n^t)$ or $U_n(n^t)$ with $\{q_{ik}\}$.

II. Constructing a new element c_{ki}

For each i, construct its new element c_{ki} according to the following formula,

$$c_{ki} = (2q_{ki} - 1)/(2n). \tag{1}$$

III. Constructing uniform sampling points for the mixtures, x_{ki}

$$x_{ki} = (1 - c_{ki}^{\frac{1}{s-i}}) \prod_{j=1}^{i-1} c_{kj}^{\frac{1}{s-j}}, \ i = 1, \ldots, s-1. \quad x_{ks} = \prod_{j=1}^{s-1} c_{kj}^{\frac{1}{s-j}}, \ k = 1, \ldots, n. \tag{2}$$

Thus, $\{x_{ki}\}$ gives the corresponding uniform design table $UM_n(n^s)$ of the mixture under the conditions of s and n.

C) Portfolio investment problem

According to Markowitz's study, the return rate function f1 and the risk function f2 could be introduced, and their expressions are, respectively,

$$f_1 = E(R) = \sum_{i=1}^{s} x_i \mu_i \ , \tag{3}$$

$$f_2 = [(x_1\sigma_1)^2 + (x_2\sigma_2)^2 + (x_3\sigma_3)^2 + \ldots + (x_n\sigma_n)^2 + \gamma_{1,2}(x_1\sigma_1)(x_2\sigma_2) + \gamma_{1,3}(x_1\sigma_1)(x_3\sigma_3) + \gamma_{1,4}(x_1\sigma_1)(x_4\sigma_4) + \ldots + \gamma_{i,j}(x_i\sigma_i)(x_j\sigma_j) + \ldots + \gamma_{s-1,s}(x_{s-1}\sigma_{s-1})(x_s\sigma_s)]^{0.5}. \tag{4}$$

In Eq. (3), μ_i is the rate of return of the *i-th* security and *s* is the total number of the securities. In Eq. (4), $\gamma_{i,j}$ is the correlation coefficient between the *i-th* security and the *j-th* security; σ_i is the risk of the *i-th* security.

According to the objective evaluation in probability - based multi - objective optimization methodology (Zheng et al, 2022a), f_1 exhibits the bigger the better, which therefore belongs to the beneficial objective, and f_2 manifests the smaller the better, which thus belongs to the unbeneficial objective, respectively.

Therefore, the answer to the portfolio problem is the optimization of a bi-objective problem. Furthermore, probability - based multi - objective optimization methodology can be used to assess it reasonably. Of course, all the evaluations in probability - based multi - objective optimization methodology can be applied rationally.

Applications

In this section, an example illustrates the use of the above steps for solving the portfolio investment problem.

Take a combination of four securities, i.e., securities *A*, *B*, *C,* and *D* as a typical example. The specific optimization process is explained in detail.

Let the expected rate of return of Security *A* be $\mu_1 = 11.29\%$, and let its standard deviation of return be $\sigma_1 = 24.53\%$; let the expected rate of return of Security B be $\mu_2 = 18.10\%$, and let its standard deviation of return be $\sigma_2 = 19.94\%$; let the expected rate of return of Security C be $\mu_3 = 8.29\%$, and let its standard deviation of return be $\sigma_3 = 11.80\%$; and let the expected rate of return of Security D be $\mu_4 = 11.52\%$, with its standard deviation of return of $\sigma_4 = 12.75\%$. Furthermore, it is assumed that the following correlation coefficients between two of the above securities are $\gamma_{1,2} = 0$, $\gamma_{1,3} = 0.68$, $\gamma_{1,4} = 0$, $\gamma_{2,3} = 0$, $\gamma_{2,4} = 0$, $\gamma_{3,4} = 0$.

Now we need to make a decision of simultaneous optimization of both the maximization of the rate of return and minimization of the variance of the rate of return on this portfolio investment.

Solution

In this section, the problem of "portfolio" is analyzed based on probability - based multi - objective optimization methodology. This is a typical bi-objective optimization problem.

Let x_1, x_2, x_3 and x_4 be the investment percentages of four securities, *A*, *B*, *C* and *D*, respectively. There is actually a constraint condition for this problem, i.e., $x_1 + x_2 + x_3 + x_4 = 1$; therefore, it has actually three independent variables, namely x_1, x_2 and x_3.

Since the sampling points of this bi-objective optimization problem are positioned in the 4 – dimensional space, it is necessary to include at least 23 sampling points with the characteristics of the "good lattice point" in the effective region for the discretization of data processing (Yu et al, 2022; Zheng et al, 2022a; Zheng et al, 2022b).

According to Fang et al (2018), this is a "uniform design for experiments with mixtures" problem due to the constraint condition of the four variables. Let us take the uniform table $U^*_{23}(23^7)$ as the initial table to construct a uniform test design table $UM_{23}(23^4)$ with mixtures, as shown in Table 1.

The uniform test table $UM_{23}(23^4)$ with the mixtures of Table 1 is based on the uniform design table $U^*_{23}(23^7)$. Because here the number of variables *s equals to 4*, *and n equals to 23*, from the above rules, $x_{k1} = 1 - c_{k1}^{1/3}$, $x_{k2} = c_{k1}^{1/3} \cdot (1 - c_{k2}^{1/2})$, $x_{k3} = c_{k1}^{1/3} \cdot c_{k2}^{1/2} \cdot (1 - c_{k3})$, $x_{k4} = c_{k1}^{1/3} \cdot c_{k2}^{1/2} \cdot c_{k3}$ (Fang et al, 2018).

Furthermore, we can get the values of the rate of return function f_1 and the risk function f_2, the distribution of their partial preferable probability and their total preferable probability, as well as the ranking at the sampling points (alternative scenario), which are shown in Table 2.

Fig. 2 shows the variation of the return rate with respect to risk at the discrete sampling points. The results reflect that the 2nd discrete sampling point gives the maximum total preferable probability closely followed by the 6th sampling point; therefore, they could be taken as the optimal solution to this portfolio problem.

Regarding the 2nd sampling point, the corresponding investment ratio is $x_1'' = 0.0222$, $x_2'' = 0.3494$, $x_3'' = 0.2596$, $x_4'' = 0.3688$, which leads to the rate of return of 12.98% and the risk of 9.09%.

As for the 6th sampling point, its investment ratio is at $x_1' = 0.0871$, $x_2' = 0.4665$, $x_3' = 0.1068$, $x_4' = 0.3397$, and its obtained rate of return is 14.23% with the risk of 10.73%.

Table 1 – Uniform test table $UM_{23}(23^4)$ with the mixtures based on the uniform design table $U^*_{23}(23^7)$
Таблица 1 – Таблица унифицированного теста $UM_{23}(23^4)$ с вариантами, основанными на таблице унифицированной модели $U^*_{23}(23^7)$
Табела 1 –Табела униформног теста $UM_{23}(23^4)$ са варијацијама заснованим на табели униформног дизајна $U^*_{23}(23^7)$

No.	q_{10}	q_{20}	q_{30}	c_1	c_2	c_3	x_1	x_2	x_3	x_4
1	11	17	19	0.4565	0.7174	0.8044	0.2300	0.1178	0.1276	0.5246
2	**22**	**10**	**14**	**0.9348**	**0.4130**	**0.5870**	**0.0222**	**0.3494**	**0.2596**	**0.3688**
3	9	3	9	0.3696	0.1087	0.3696	0.2824	0.4810	0.1492	0.0874
4	20	20	4	0.8478	0.8478	0.1522	0.0535	0.0750	0.7389	0.1326
5	7	13	23	0.2826	0.5435	0.9783	0.3438	0.1725	0.0105	0.4733
6	**18**	**6**	**18**	**0.7609**	**0.2391**	**0.7609**	**0.0871**	**0.4665**	**0.1068**	**0.3397**
7	5	23	13	0.1957	0.9783	0.5435	0.4195	0.0063	0.2621	0.3121
8	16	16	8	0.6739	0.6739	0.3261	0.1233	0.1570	0.4850	0.2347
9	3	9	3	0.1087	0.3696	0.1087	0.5228	0.1871	0.2586	0.0315
10	14	2	22	0.5870	0.0652	0.9348	0.1627	0.6235	0.0139	0.1999
11	1	19	17	0.0217	0.8043	0.7174	0.7209	0.0288	0.0707	0.1796
12	12	12	12	0.5	0.5	0.5	0.2063	0.2325	0.2806	0.2806
13	23	5	7	0.9783	0.1957	0.2826	0.0073	0.5536	0.3150	0.1241
14	10	22	2	0.4130	0.9348	0.0652	0.2553	0.0247	0.6731	0.0470
15	21	15	21	0.8913	0.6304	0.8913	0.0376	0.1982	0.0831	0.6811
16	8	8	16	0.3261	0.3261	0.6739	0.3117	0.2953	0.1282	0.2649
17	19	1	11	0.8043	0.0217	0.4565	0.0700	0.7929	0.0745	0.0626
18	6	18	6	0.2391	0.7609	0.2391	0.3793	0.0793	0.4119	0.1295
19	17	11	1	0.7174	0.4565	0.0217	0.1048	0.2903	0.5917	0.0131
20	4	4	20	0.1522	0.1522	0.8478	0.4661	0.3256	0.0317	0.1766
21	15	21	15	0.6304	0.8913	0.6304	0.1425	0.0479	0.2992	0.5104
22	2	14	10	0.0652	0.5870	0.4130	0.5975	0.0941	0.1810	0.1274
23	13	7	5	0.5435	0.2826	0.1957	0.1839	0.3822	0.3490	0.0849

Table 2 – Evaluation results of the rate of return f_1, the risk f_2, the preferable probability and the ranking at the sampling points

Таблица 2 – Результаты оценки ставки доходности f_1, риска f_2, предпочтительной вероятности и ранжирования по точкам выборки

Табела 2 – Резултати процене стопе приноса f_1, ризика f_2, пожељне вероватноће и рангирање по тачкама узоркованја

No.	Values of f_1 and f_2		Partial preferable probability		Overall preferable probability	Rank
	f_1	f_2	P_{f1}	P_{f2}	$P_t \times 10^3$	
1	0.1183	0.0979	0.0417	0.0510	2.1241	9
2	**0.1298**	**0.0909**	**0.0457**	**0.0533**	**2.4346**	**1**
3	0.1414	0.1268	0.0498	0.0416	2.0703	11
4	0.0961	0.0992	0.0337	0.0506	1.7125	17
5	0.1254	0.1099	0.0442	0.0471	2.0800	10
6	**0.1423**	**0.1073**	**0.0501**	**0.0479**	**2.4017**	**2**
7	0.1062	0.1321	0.0374	0.0397	1.4907	18
8	0.1096	0.0917	0.0386	0.0530	2.0452	12
9	0.1180	0.1552	0.0415	0.03234	1.3434	20
10	0.1554	0.1334	0.0547	0.0395	2.1591	6
11	0.1132	0.1841	0.0399	0.0229	0.9142	23
12	0.1210	0.0968	0.0426	0.0514	2.1880	5
13	0.1414	0.1179	0.0498	0.0445	2.2152	4
14	0.0945	0.1306	0.0333	0.0404	1.3433	21
15	0.1255	0.0970	0.0442	0.0513	2.2663	3
16	0.1298	0.1107	0.0457	0.0468	2.1404	7
17	0.1648	0.1601	0.0580	0.0308	1.7848	16
18	0.1062	0.1330	0.0374	0.0396	1.4806	19
19	0.1150	0.1064	0.0405	0.0482	1.9519	14
20	0.1345	0.1356	0.0474	0.0387	1.8348	15
21	0.1084	0.0921	0.0382	0.0529	2.0187	13
22	0.1142	0.1637	0.0402	0.0296	1.1893	22
23	0.1287	0.1104	0.0453	0.0469	2.1267	8

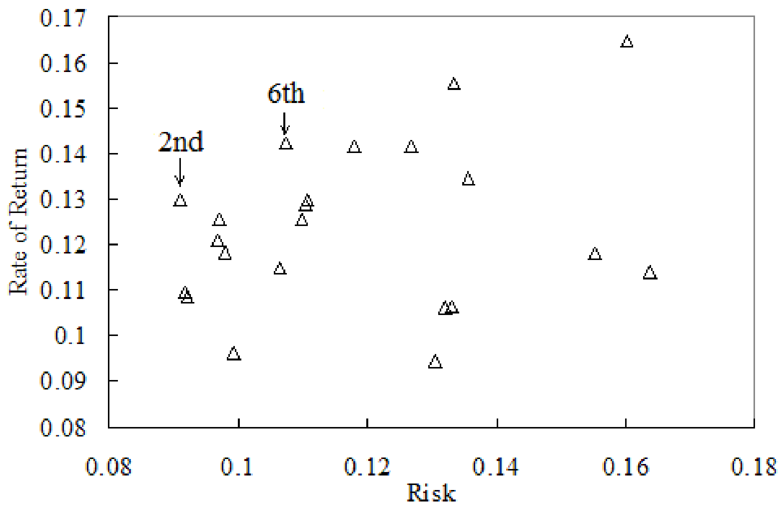


Figure 2 – Variation of the return rate with respect to the risk at the discrete sampling points

Рис. 2 – Варианты ставки доходности по сравнению с риском в дискретных точках выборки

Слика 2 – Варијација стопе приноса у односу на ризик у тачкама дискретног узорковања

Conclusion

In this paper, the probability-based multi-objective optimization method is combined with uniform design for experiments with mixtures to study the portfolio investment problem, which aims to give a rational approach to handling the problem of simultaneous optimization of both maximizing the rate of return and minimizing the variance of the rate of return; the analysis shows that probability - based multi - objective optimization methodology could provide the optimal solution with the characteristics of simultaneous optimization of both maximizing the rate of return and minimizing the variance of the rate of return; uniform design for experiments with mixtures could be used to properly conduct discretization for data processing and simplification.

References

Fang, K.-T., Liu, M.-Q., Qin, H. & Zhou, Y.-D. 2018. *Theory and Application of Uniform Experimental Designs.* Singapore: Springer. Available at: https://doi.org/10.1007/978-981-13-2041-5.

Nisani, D. & Shelef, A. 2021. A statistical analysis of investor preferences for portfolio selection. *Empirical Economics*, 61, pp.1883-1915. Available at: https://doi.org/10.1007/s00181-020-01947-8.

Oberoi, S., Girach, M.B. & Chakrabarty, S.P. 2020. Can robust optimization offer improved portfolio performance? An empirical study of Indian market. *Journal of Quantitative Economics*, 18, pp.611-630. Available at: https://doi.org/10.1007/s40953-020-00205-z.

Sarmas, E., Xidonas, P. & Doukas, H. 2020. *Multicriteria Portfolio Construction with Python*. Cham, Switzerland: Springer. Available at: https://doi.org/10.1007/978-3-030-53743-2.

Wang, S. 2022. *Securities Investment: Theory and Practice*. Beijing, China: Science Press (in Chinese). ISBN: 9787030630469.

Yu, J., Zheng, M., Wang, Y. & Teng, H. 2022. An efficient approach for calculating a definite integral with about a dozen of sampling points. *Vojnotehnički glasnik/Military Technical Courier*, 70(2), pp.340-356. Available at: https://doi.org/10.5937/vojtehg70-36029.

Zheng, M., Teng, H., Yu, J., Cui, Y. & Wang Y. 2022a. *Probability-Based Multi-objective Optimization for Material Selection.* Singapore: Springer. Available at: https://doi.org/10.1007/978-981-19-3351-6.

Zheng, M., Teng, H., Wang, Y. & Yu, J. 2022b. Appropriate Algorithm for Assessment of Numerical Integration. In: *2022 International Joint Conference on Information and Communication Engineering (JCICE)*, Seoul, Republic of Korea, pp.18-22, May 20-22. Available at: https://doi.org/10.1109/JCICE56791.2022.00015.

Инвестиционный портфель, основанный на вероятностной многоцелевой оптимизации и унифицированной модели с вариационными экспериментами

Маошенг Чжэн[а], *Джи* Йю[б]

Северо-западный политехнический университет, г. Сиань, Народная Республика Китай

[а] факультет химической инженерии, **корресподент**

[б] факультет естественных наук

РУБРИКА ГРНТИ: 27.47.00 Математическая кибернетика,
27.47.19 Исследование операций
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье представлен новый подход к решению задач инвестиционного портфеля путем одновременной оптимизации максимизации ставки доходности и минимизации дисперсии ставки доходности. Обработка выполняется путем сочетания вероятностной многокритериальной оптимизации с унифицированной моделью вариационных экспериментов.

Методы: Вероятностная многокритериальная оптимизация в основном используется при сочетании двухкритериальной задачи одновременной оптимизации максимизации ставки доходности и *минимизации дисперсии ставки доходности в однокритериальной задаче общей предпочтительной вероятности по каждому альтернативному сценарию. Общая предпочтительная вероятность является произведением всех частных вероятностей предпочтительной полезности производительности, поэтому метод унифицированной модели вариационных экспериментов используется при создании множества эффективных точек выборки для решения задачи инвестиционного портфеля с целью достижения дискретизации при обработке данных и упрощения процедуры, в которой пропорция x_i подчиняется условию ограничения $x_l + x_2 + x_3. . . + x_s = 1$ с общим числом переменных s для x_i.*

Результаты: В решении задач инвестиционного портфеля используется новый подход, который по сути представляет собой одновременную оптимизацию максимизации ставки доходности и минимизации дисперсии ставки доходности, что приводит к разумным результатам. Результаты обладают качеством рациональности с точки зрения теории вероятностей для одновременной оптимизации нескольких целей.

Выводы: Настоящий метод естественным образом отражает суть проблемы инвестиционного портфеля и дает новый способ решения важнейшей задачи.

Ключевые слова: задача инвестиционного портфеля, многокритериальная оптимизация, предпочтительная вероятность, дискретная выборка, теория вероятностей.

Инвестициони портфолио заснован на пробабилистичкој вишекритеријумској оптимизацији и униформном дизајну за експерименте са варијацијама

Маошенг Ценг[а], *Ђаи* Ју[б]

Универзитет Северозапад, Сијан, Народна Република Кина

[а] Факултет хемијског инжењерства, **аутор за преписку**

[б] Факултет природних наука

ОБЛАСТ: математика, рачунарске науке
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Формулисан је нови приступ решавању проблема инвестиционог портфолија помоћу истовременог оптимизовања максимизације стопе приноса и минимизације варијансе стопе приноса. Процесирање се изводи комбинацијом вишекритеријумске оптимизације засноване на вероватноћи са униформним дизајном за експерименте са варијацијама.

Методе: Вишекритеријумска оптимизација заснована на вероватноћи превасходно се користи да се двокритеријумски проблем истовременог оптимизовања максимизације стопе приноса и минимизације варијансе стопе приноса синтетише у једнокритеријумски проблем укупне пожељне вероватноће сваког алтернативног сценарија. Укупна пожељна вероватноћа је производ свих парцијалних пожељних вероватноћа корисности сваке перформансе. Дакле, метод униформног дизајна за експерименте са варијацијама користи се за креирање скупа ефективних тачака узорковања за проблем инвестиционог портфолија како би се постигла дискретизација у процесирању података и поједноставио поступак у којем пропорција x_i следи услов ограничења $x_l + x_2 + x_3 . \ . \ . + x_s = 1$ са укупним бројем варијабли s за x_i.

Резултати: Нови приступ користи се за решавање проблема инвестиционог портфолија који, у суштини, представља истовремено оптимизовање максимизације стопе приноса и минимизације варијансе стопе приноса, што води до разумљивих последица. Резултати имају квалитет рационалности са становишта теорије вероватноће за истовремену оптимизацију вишеструких циљева.

Закључак: Овај метод природно одсликава суштину проблема инвестиционог портфолија и пружа нов начин за његово решавање.

Кључне речи: проблем инвестиционог портфолија, вишекритеријумска оптимизација, пожељна вероватноћа, дискретно узорковање, теорија вероватноће.

Paper received on / Дата получения работы / Датум пријема чланка: 18.12.2022.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 05.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 07.06.2023.

Modeling of combat operations

Mladen S. Kostić[a], *Aca* D. Jovanović[b], *Mitar* V. Kovač[c]

Educons University, Faculty of Project and Innovation Management, Belgrade, Republic of Serbia

[a] e-mail: rockymladenkostic@gmail.com, **corresponding author**, ORCID iD: https://orcid.org/0009-0009-3277-7256

[b] e-mail: aca.jovanovic@pmc.edu.rs, ORCID iD: https://orcid.org/0000-0003-2284-5875

[c] e-mail: mitar.kovac21@gmail.com, ORCID iD: https://orcid.org/0009-0007-6591-6043

DOI: 10.5937/vojtehg71-43509; https://doi.org/10.5937/vojtehg71-43509

FIELD: mathematics, military science
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The goal of the research in this paper is to present and evaluate the method of modeling operations by aggregating forces by simulating the battle process with Lanchester's equations. This method is the software basis of a certain number of programs used in NATO, in war simulations, and in the planning and analysis of operations. Its value is in understanding the consequences of decisions made with outcomes and results of combat actions.

Methods: The case study of the well-known Operation Desert Storm gathered the necessary data on operational parameters and the way forces are used in battles. The obtained data were transformed into operational variables of the combat model using the force aggregation method, whose simulation was carried out using the method of differential Lanchester's equations (quadratic law).

Results: By simulating the modeled operation, the parameters of the outcome of the conflict were obtained with numerical indicators of success, consumption of resources, etc. The results were analyzed and a certain correlation with the parameters of the real operation was determined, which enables the validation of the model.

Conclusion: The partial validity of the model describing the conflict on a practical historical example from a case study was confirmed. There are objective limitations in the application of modeling of military operations and optimization of the use of forces. The value of this method is the possibility of a reliable strategic assessment of the adversary's military power at the strategic level.

Key words: air/ground combat operations, attrition, aggregated forces model.

Introduction

The method of modeling and simulation is a scientific tool for visualizing operation plans and predicting the course and the outcome of combat operations. However, in most cases, planners do not know the mathematical background of the program responsible for obtaining results. This can result in subconsciously rejecting the obtained results as unreliable or in giving them too much importance even though there is no basis for either of these.

War and armed conflicts are not a part of the past and will never be. The problem of war is not its occurrence, but wrong decisions made on the assessment of the outcome of the conflict only on the basis of armchair experience and the knowledge of battles from epic history. This often leads to disasters. Examples for this claim are, in addition to Desert Storm which ended disastrously for Iraq, the recent Coalition campaigns in Libya, Iraq and Afghanistan. Finally, the Russian special operation in Ukraine is the last example, but certainly a representative one.

The aim of the research in this paper is to validate the method of modeling the battle process with Lanchester's equations by aggregating heterogeneous forces into homogeneous ones, with the aim of applying it as a scientific tool in the process of planning and analyzing operational-strategic operations. The value of modeling and simulation lies in the simplicity of viewing the consequences of the decisions made in correlation with the essential operational parameters of the results of implementation and the final outcome. This deepens theoretical knowledge about strategy and operational art, which contributes to the verification of the planning process and the predictability of conflict outcomes. The results are noticeable in the preparation and execution of combat operations, their efficiency and effectiveness, assessment of operational capabilities, advantages of new technologies, tactics and purposeful decision making.

The second part of the paper gives the theoretical foundations of the methods used, Lanchester's square law of combat and studies of the equivalence of forces by aggregating heterogeneous forces into homogeneous ones. A brief historical review is given with practical examples of application in solving real combat and practical problems, as well as shortcomings and their evolution into approximate models for software application in computers.

In the third part, experimental modeling was carried out - Operation Desert Storm. The model considered abstracted parameters on the influence of operational factors, combat capabilities, heterogeneity and number of forces, needed for validation, prediction of outcome and course of action, converting them into equivalent values.

The fourth part contains the result analysis and the discussion of their correlation with the actual facts of war, as well as the principles of the quadratic laws of the battle, derived from Lanchester equations. After verification, the validation of the applied methods was made, based on the obtained results and historical facts.

Theoretical background

Lanchester - Osipov's mathematical model, widely known as Lanchester's equations or the law of combat, represents one of the first attempts to scientifically describe armed combat. Lanchester (1916) uses his equations to describe two historical types of combat, which characterizes the process of depletion of forces, influenced by two quantities: the strength of forces and the fighting capability, expressed by the Lanchester attrition-rate coefficient. The first combat type is linear and represents ancient and medieval battles, characterized by the use of cold weapons on foot or on horseback and sometimes by the use of archers, catapults and similar ancient weapons. The analytical expression for this process is (Washburn et al, 2022) where (α) and (β) represent the attrition rates and (X) and (Y) are the numbers of forces engaged in combat:

$$\frac{dX}{dt} = -\beta \qquad \Lambda \qquad \frac{dY}{dt} = -\alpha, \tag{1}$$

for $X > 0 \;\; \Lambda \;\; Y > 0$

The second type of combat is described by Lanchester's square law which characterizes modern combat and warfare with the massive use of firearms, emphasizing the decisive influence of concentration of forces. The general idea (Kress, 2020) in the Lanchester model is to define the variables of the numerical state of the armed forces and the coefficients of the rate of inflicting losses on the adversary, and then solve the resulting equations as a function of time. If there is no change in time for the attrition rates (α) and (β), then the differential equations can be expressed as a system of ordinary differential equations (Washburn, 2000):

$$\frac{dX}{dt} = -\beta * Y \qquad \Lambda \qquad \frac{dY}{dt} = -\alpha * X, \tag{2}$$

for $X > 0 \;\; \Lambda \;\; Y > 0$

Even in the case where both sides have the same attrition rate or one is slightly better, the advantage in force numbers has a decisive influence

(MacKay, 2006). This implies: the winner is the side with better force concentration at the right moment and the right place or maybe has a bigger unit's army divisions or air squadrons (Lanchester, 1916).

A special form of Lanchester's linear law is area combat. It consists of operations characterized by the law of probability without precision shooting, such as artillery bombardment or air support of an area, which is evenly occupied by opposing armed forces. The side that opens fire inflicts losses on the other side at a certain rate, proportionally to the number of forces located on a certain area, in relation to the total area of the combat layout (Washburn et al, 2022).

Another special form is the logarithmic law of combat, which refers to taking into account other reasons for depleting forces, such as illness, natural disasters, desertion, etc. (Washburn et al, 2022). It is interesting that this particular model proved to be more accurate than the others.

Lanchester's differential equations are the basis for the application of the slightly more complex Deitchman 's (1962) law of mixed combat, which enables the simulation of the combat dynamics of qualitatively different opponents such as the warfare of two adversaries in guerrilla and conventional combat. This problem could be solved by a combination of quadratic and linear laws (Darcom Pamphlet, 1979). A new aspect of the problem of this kind of conflict was given by Kress (2020) by including collateral victims among civilians. Many published works on historical battles partially validated the model which was successfully used to solve certain practical problems. The examples include: Iwo Jima (Engel, 1954), Ardennes campaign (Fricker, 1997) and Kursk (Lucas & Turkes, 2004), artillery and air support; strategy optimization in relation to weapon range, enemy attrition rate and operational costs (Isaacs, 1965); solving air operations problems in terms of combat resources due to the distribution of combat sorties in air support operations, offensive and defensive anti-aircraft operations (Berkovitz and Dresher, 1959), SEAD operations (Barkdoll et al, 2002) and the high level of engagement of the air battle model and expenditure design process (Allen, 1993).

The flaw in the basic model methodology was noticed quite early on. Osipov (Helmbold & Rehm, 1995) immediately pointed out the problem of a constant rate of expenditure of forces, which does not take into account the influence of various parameters such as: maneuver, tactical decisions, logistics, shooting process, operational situation factors (weather, geography, etc.). For these reasons, and in order to improve the initial method, combat modeling by partial differential equations was developed (Protopopescu et al, 1990). Using these methods, even the contribution of intelligence support can be determined (Coulson, 2019). An interesting war model created by Seung-Won Baik (2013) is based on a multi-weapon expansion. Helmbold (1965) noted that the relative rate of attrition of opposing forces depends on the ratio of force sizes. It is also important to mention Bonder (1970), who considered the combat range as a function of time with a constant rate of change of distance.

The fact is that Lanchester's equations and their refinements have been applied with some success in the analysis of historical battles, solving logistical and other operational problems. However, despite the improvements, the basic problem of combat modeling of the heterogeneous structure of forces in battle, in the conditions of changing operational factors, remained. In accordance with the fact that warfare represents a conflict of different types of armed forces, modeling of real warfare implies a heterogeneous combat structure of forces. Given these facts, it is understandable why the application of the basic Lanchester model is not suitable for modeling real war combat.

Another reason is that there is a fundamental difference between modeling the combat of smaller forces versus large, complex forces. The first case is a detailed simulation of each combat entity in the simulation, which is often defined as a high-resolution model approach and can be expressed by several differential equations which describe the combat process. The second case requires many more equations, with more detail. High resolution models involve complex computer programs. Their development and maintenance are complex and expensive. They are usually stochastic, which seems desirable, but actually requires replication to get answers about simulated combat. When trying to model larger forces (divisions, armies, etc.), the number of armed entities makes it impossible to maintain individual resolution.

As Taylor (1980a) said "for small-scale operations it may be possible to reasonably represent force interactions and attendant attrition rates with a few differential equations, but for large-scale operations of conventional armed forces the same approach might well involve hundreds (and possibly even thousands) of differential equations tied together through battlefield operations". On the basis of these arguments considering methodology complexity for practical solving of this problem, Taylor (1980a) emphasized there were only few developed useful analytical models. Furthermore, he asserts three main approaches in simulating the combat model based on attrition:

- Monte-Carlo simulation,
- Aggregated Force-Fire Power Score approach, and
- Detailed Lanchester's type model.

For modeling large scale combat operations such as strategic combined operations or campaigns, more suitable are Aggregated Force and Detailed Lanchester's type model. Monte-Carlo simulation is more suitable for small scale combat models (bellow the battalion force level). Disregarding the difference of stochastic and deterministic nature between these methods, a lot of authors consider both models quite similar in sense of results but the deterministic model is more practical for use (Taylor, 1980a).

In general, many experts believe that deterministic models, applicable on computers, give on average similar results to stochastic models, while being more practical. An illustrative description of the problem, by Taylor (1980a), is the consideration of the combat of heterogeneous forces with different types of combat systems with capabilities expressed by the attrition.

In this model of combat, there are a few assumptions which must be considered:

- attrition effects on forces are additive for every specific combat element, without mutual support and synergy effects,
- attrition efficiency of any combat system is proportional to the number of elementary units of that type, and
- each part of forces will attrite all available elements of the opponent according to its own combat capability.

Fire distribution can be considered as special factors (Ψ_{ij}) and (ϕ_{ij}), for both opponents, referring to a part of the forces of one side destroying a part of the forces of the other side, where:

$$X_i > 0,\ Y_j > 0 \quad \Lambda \quad 0 < \phi_{\mathrm{ij}},\ \psi_{\mathrm{ij}} < 1.$$

According to this and (eq.2), the final model is:

$$\frac{dX_i}{dt} = -\sum_{j=1}^{n} \psi_{ij} * b_{ij} * Y_j \qquad \Lambda \qquad \frac{dY_j}{dt} = -\sum_{i=1}^{m} \phi_{ij} * a_{ij} * X_i \tag{3}$$

This is a combat model where two opponents have heterogenic structures (Taylor, 1980a). The problem seems very simple to solve but that is illusion, because the real solution is very complex, even impossible to resolve. It becomes obvious when someone tries to resolve the combat model of two opponent forces with three and more combat elements (Hsiao & Guu, 2004).

The approximate methods are based on developed procedures for solving the model numerically. Significant contributions to the development of Aggregated Combat Models methodology are the works of: Alan

Washburn, Bill Caldwell, Jim Hartman, Sam Parry and Mark Youngren (Washburn et al, 2022). The numerical approach enables complex problems solving where analytical methods cannot help. They allow solving complex problems for which the solutions satisfy a certain degree of accuracy, which means that there is a certain error with some degree but which is within the limits of tolerance in relation to the analytical solution. Aggregated-force modeling was the basis of various simulation programs of war games, which are still used around the world today, which is why it will be tested as a model base in this work.

Aggregated-force modeling

The basic idea of this model is to aggregate all individual combat elements in the unit into one scalar measure that represents the combat power of the unit. This method combines various weapon systems and forces into one homogeneous force, using two characteristic quantities: the Firepower Index - (FPI) and the Firepower Score - (FPS).

The term firepower score indicates the combat power for each type of a particular weapon system. The firepower index indicates the summarized result, that is, the combat capability of the total, aggregate forces of a unit (Taylor, 1980b). In order to obtain the FPI, a linear model is used to transform all special values of the coefficients of the rate of inflicting losses on the other side, as an aggregate FPS, for the total, combined forces. Also, it is important to emphasize that the conceptual-categorical apparatus is uneven and that different authors use different terms with the same meaning. Since aggregate forces consist of completely different weapon systems, in order to achieve standardization for comparing different systems, the fundamental principle for determining the value is directly proportional to the value of the enemy system it destroys.

Calculating the FPS is relatively complex (Holter,1973), which also complicates the methodological unevenness of this method (Taylor, 1980b). The problem in studies of equivalent forces, as this methodological approach is also called, is to determine the weight or value of all types of weapons of each side in the conflict. Therefore, if we assume that the total value of different, combined weapons systems is a linear function of all those different systems, then it can be expressed by the following Aggregation of Forces (Taylor, 1980b):

$$s_i^x = k_x \cdot \sum_{j=1}^{n} b_{ji} * s_j^y \qquad \Lambda \qquad s_j^y = k_y \cdot \sum_{i=1}^{n} a_{ij} * s_i^x \tag{4}$$

for: $a_{ij} > 0 \;\; \Lambda \;\; b_{ji} > 0$

Where (s_i^x) or (s_j^y) represent the value of one (X_i) or (Y_j) weapon system of the same type on one side which is directly proportional to the total value of the opposing forces destroyed by those weapons per unit of time. This means that aside from constants of proportionality (k_x) and (k_y), the kill rate matrix (b_{ji}) denotes the attrition rate at which one (Y_j) system kills or destroys (X_i) systems in a certain combat situation and vice versa.

In relation to the initial analytical form of the battle of heterogeneous forces (eq.3), we consider the total value of the opposing forces (X) and (Y), as the value or the FPI of (V_x) and (V_y). Then the FPI represents the combat potential or the value of a military unit, where the score or the sum of that is a weapon system and indicates the number of combat elements in the unit:

$$V_x = \sum_{i=1}^{m} s_i^x * x_i \qquad \Lambda \qquad V_y = \sum_{j=1}^{n} s_j^y * y_i \tag{5}$$

The values of the constant of proportionality (k_x) and (k_y) from (eq.4) are more convenient to be expressed as (Taylor, 1980b):

$$\left(\frac{1}{K_x}\right) = c_x \qquad \Lambda \qquad \left(\frac{1}{K_y}\right) = c_y \tag{6}$$

In that case, the intensity of combat losses of aggregate forces (X) and (Y) and the values (c_x) and (c_y) can be interpreted as the Lanchester coefficient of attrition rate of loss of composite forces in the process where aggregate forces are consumed with time. The meaning of these constants is a direct consequence of the premise that there are positive values (c_x) and (c_y) which can determine the relationships between the values of different weapons or the FPS (s_i^x) and (s_j^y).

Finally, according to Taylor (1980b), it follows that the ratio expresses the equality of the average infliction of losses in time of (X) or (Y) sides as $(\frac{d\bar{Y}}{dt})$ or as $(\frac{d\bar{X}}{dt})$ and the product of the negative constant ($-c_y$) or ($-c_x$) and the average "weight" of the other and represents a unique value for all types of weapons. This can be written, in terms of Lanchester's square law, as:

$$\frac{dV_x}{dt} = -c_y * V_y \qquad \Lambda \qquad \frac{dV_y}{dt} = -c_x V_x \tag{7}$$

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2023, Vol. 71, Issue 3

This also means that if it is possible to determine the values (c_x) and (c_y) and the FPS vectors $[s^x]$ and $[s^y]$ of the total aggregated forces FPI in the time (V_x) and (V_y), by transformation of a heterogeneous conflict model into a homogeneous one, the mathematical model can be expressed as the classic Lanchester's quadratic law of combat (Darcom Pamphlet, 1979):

$$V_x(t) = V_x^0 cosh\sqrt{c_y * c_x * t} - V_y^0 \sqrt{\frac{c_y}{c_x}} \cdot sinh\sqrt{c_y * c_x * t} \qquad (8)$$

According to Taylor (1980b), this calculation is repeated for all parts of the forces if they are geographically separated and the losses actually represent a daily (temporal) decrease in combat power caused by combat operations. Individual losses, of special parts of power, are obtained through the process of disaggregation (Taylor, 1980b).

Algorithm for obtaining the FPS and the FPI[1]

The starting point of the procedure is based on the value of the equivalent forces by the equation:

$$C^2 * [a_{ij}] * [b_{ji}] * [S_i^x]^k = [W_i]^k \qquad (9)$$

Where $[S_i]^k$ is a new vector defined as a relative value – the FPS of the (*i*) weapon type (Darcom Pamphlet, 1979) and (*C*) is the single scaling factor for convenience, which brings the arms of real values into relation (Holter, 1973). Sizes indicate the relative value of individual weapons. For example, in relation to the value - a tank, so it can be concluded that some Blue type (*A*) weapons are effectively similar to Red type (*B*) weapons and each worth as two tanks (M60A3).

At the beginning, all components of the FPS vector $[s_i^x]^k$ are determined to have a value one, where the exponent *(k=1)* denotes the start of the iterative process. According to Holter (1973), this yields a fast convergent algorithm, leading to a unique value(Λ) and the FPS- $[S_i^x]^k$. By calculating (eq.9), a new vector – a relative FPS $[W_i]^k$is obtained, in which the weakest component (infantry) $[S_{inf}]^k$, is determined as the equivalent force value in relation to which other elements are determined.

[1] Considering the methodological complexity of the procedure for obtaining the rating and the index of firepower, it is not suitable and possible to give a detailed description; however, the essence of the method is shown. For more detailed information, see the works of Taylor (1980), Holter (1973) and a group of authors in the Handbook (Darcom Pamphlet, 1979), where the method is fully and thoroughly presented, with appropriate examples.

Then a new FPS is calculated according to the following relation:

$$[S_i]^{k+n} = \Lambda^k * [W_i]^k , \tag{10}$$

$$where: \quad \Lambda^k = {}^1/_{(S_{inf})^k} \tag{11}$$

where $[S_i]^{k+n}$ is the next vector of the relative FPS and where e.g.$(S_i)^k$ - infantry is the weakest weapon component.

The previous step (eq.9) is repeated, increasing (k) by a unit at each iteration, until the value: $\Lambda^{k+n+1} \approx \Lambda^{k+n}$, at some stage or iteration (k) is within a certain degree of accuracy. The iterations converge to a unique value (Λ) and the vector $[s_j^y]$ under the assumption that the matrix with $[a_{ij}$] * $[b_{ji}$] is irreducible (Darcom Pamphlet, 1979).

After the last iteration, the final value for (Λ) and the vector $[s_i^x]$ is reached:

$$[s_i^x]^{k+n+1} = \Lambda^{k+n} * [W_i]^{k+n} \tag{12}$$

Finally, the FPS $[s_j^y]$ is calculated:

$$C * [b] * [s_i^x] = \left[s_j^y\right] \tag{13}$$

$$\text{where} \qquad C = \sqrt{\Lambda} \tag{14}$$

The final vectors $[s_i^x]$ and $[s_j^y]$, represent the FPS for both opponent's weapon types or classes. The total value or the Fire Power Index – FPI $V_0(X)$ and $V_0(Y)$, of both opponents, is given by the relation:

$$V_0(X) = [s_i^x]^T * [X_i] \qquad \Lambda \qquad V_0(Y) = \left[s_j^Y\right]^T * [Y_j] \tag{15}$$

This represents only the basic structure of the model, which according to Taylor (1980b) forms the basis for the software tool in various war game simulations for the operational level, such as: ATLAS, TAGS, CEM, IDAGAM and TACWAR or the more recent FATHM (Washburn & Kress 2009). This type of model is also used in this paper.

Although this method is determined by the rate of fire (product of fired projectiles and carriers) in a certain time, it is nevertheless based on a certain subjectivism in the development of the FPI and is therefore subject to certain objections. It has been criticized by several experts, due to the method of calculation, where the FPI depends on the circumstances of the way of use, which affect the effectiveness of each particular element of the forces of one of the opponents. At the same time, the quantification of the combat capabilities of each special element represents a number that indicates its value in special combat conditions, in relation to other elements.

Also, it is important to emphasize that the conceptual-categorical apparatus is uneven and that different authors use different terms with the same meaning. Since aggregate forces consist of completely different weapon systems, the fundamental principle for determining the value is directly proportional to the value of the enemy system it destroys. In order to achieve standardization for comparing different systems, this maxim is developed into the view that the value of a weapon system is directly proportional to the rate at which the value of an enemy weapon system is destroyed. According to Taylor (1980b), this has continued to be the basis for large force conflict analyses in the US Armed Forces and NATO countries during 70s and 80s and even today, due to the simple fact that it is by far the most suitable for software application. The fact is that these methods are still in use through software tools which are applied for simulations of the conflict of forces of strategic groups on the battlefield. However, it has been criticized by a lot of authors.

Due to the nature of war as a phenomenon and the limited availability of relevant facts, modeling was done followed by the evaluation of the method based on the results of a case study, a representative historical example of a strategic air operation (campaign) Operation Desert Storm (Keaney & Cohen, 1993).

Experiment – combat simulation

The essential question is both complex and difficult to answer: whether the created combat model behaves consistently in a way that corresponds to reality? The key is the assessment of the parameters that are an integral part of the model. By practical verification, on the example of a combat situation, a comparison can be made and the real applicability of the approximate method can be verified. The validation of the model was carried out by simulating the combat operation Desert Storm, due to fortunate circumstances that a large statistical material is publicly available, with a wealth of data such as: data on planning and formation of forces (Gulf War Air Power Survey, 1993a), the number of flights performed, the consumption of ammunition and fuel, the number and type of targeted objects, tactics and training and combat capabilities (Gulf War Air Power Survey, 1993c), expected effects of actions, etc. For the sake of simplicity of application and data processing, a certain approximation was made, which refers to the generalization of the forces and the determination of their combat capabilities.

Blue (Coalition Force) has m = 3 types of combat forces, which are then grouped according to their type and purpose, and deployed in the appropriate order of battle: air force, air defense and army force.

Red (Iraq Force) has n = 4 types of combat forces, which are then also grouped according to their type and purpose, and deployed in the appropriate order of battle: air force, air defense, army force and tactical ballistic missiles.[2]

The reviewed forces, according to their numerical strength status are given in the following Tables from 1 to 3 (Gulf War Air Power Surwey, 1993d) and the combat capabilities of the opponents are given in Tables 4 and 6 (Gulf War Air Power Surwey, 1993b). The ground forces are shown as a collection of elementary parts, which together form wholes of special types of combat units of mechanized and armored divisions and brigades. The Iraqi army represents: 8 divisions of the Republican Guard and 36 divisions of the Regular Army on the Kuwaiti battlefield, while armored brigades form the composition of 22 divisions of the Iraqi army in Iraq. Actual numbers of Ground combat force elements are shown in Table 3.

Table 1 – Comparative strenght of Coalition and Iraqi Forces by types
Таблица 1 – Сравнительная численность коалиционных и иракских сил по видам
Табела 1 – Упоредна снага коалиционих и ирачких снага по врстама

X_i	X_F	X_B	X_{STH}	X_{EW}	X_{FA}	X_{SEAD}	X_{AH}
	205	420	40	59	2150	450	681
Y_j	Y_F	Y_{FA}	Y_A	Y_{EW}	Y_{SEAD}	Y_{recon}	Y_{AH}
	56	164	908	20	12	32	442

Table 2 – Comparative strenght of Coalition and Iraqi Forces by types
Таблица 2 – Сравнительная численность коалиционных и иракских сил по видам
Табела 2 – Упоредна снага коалиционих и ирачких снага по врстама

X_i	X_{ADL}	X_{ADM}	X_{ADS}	X_{WMD}	X_{MD}	X_{ABr}
	96	44	-	-	24600	21000
Y_j	Y_{ADL}	Y_{ADM}	Y_{ADS}	Y_{WMD}	Y_{ArmD}	Y_{MD}
	18	270	558	110	33000	22000

[2] Meanings of abbreviations are: F-fighter, B-bomber, FB- fighter bomber, STH-stealth, EW-electronic warfare, FA-fighter attack, SEAD-suppression of enemy air defense, AH-attack helicopter, ADF-air defense (L-long, M-medium, S-short range), A-artillery, E-infantry, ARM-armored; T-tanks, AFV-armored fighting vehicles, WMD-weapons of mass destruction, MD-Mechanized divisions, ABr-Armored Coalition' s brigades, ArmD-Iraqi' s armored divisions, MD-Mechanized divisions.

Table 3 – Comparative formation composition of ground forces by types
Таблица 3 – Сравнительный структурный состав сухопутных войск по видам
Табела 3 – Упоредни формацијски састав копнених снага по врстама

	T	AFV	Artillery	Infantry
X_i	7716	13160	4556	486400
Y_j	6490	4620	4151	330000

The method implies that through the process of aggregation of forces, the values of the equivalent forces FPS and FPI of both opponents are defined, considering the rate of attrition through operational capabilities Bulger (1997). After that, the combat model is programmed with a set of analytical equations which describe the "attrition" or combat losses of each opponent's forces, according to the Lanchester quadratic law of combat (Eq.8). Each separate element of the aggregate forces is recalculated by the reverse process, according to a given time step in the operation or campaign.

When modeling with this method, the following assumptions were made:

- the impact of the force maneuver is related to the speed of expenditure of forces and has no other influence,
- there is no change in the rate of attrition of force, during the execution of a special stage or sequence of the operation,
- there is no operational pause during combat engagement,
- all combat forces of both opponents are simultaneously engaged in combat until the desired end state is achieved: neutralization, defeat or retreat, and
- air operations on strategic targets were not considered, such as air strikes on logistics bases, warehouses, energy plants, etc.

The combat capabilities of the forces in this case mean the speed of inflicting losses by a certain combat system of one party to a certain combat system of the other party. They are given in Tables from 4 to 6.

In the mentioned simulations, which were used or are still used by NATO member armies, it is possible to program different operational situation conditions and types of combat: such as attack or defense, maneuver combat, winter or summer, mountainous terrain, surprise, etc. This is important to note because in these cases the composition and the number of forces changes, as well as the combat capabilities of special elements of the forces, which affects the aggregation of forces and the Firepower Index or Value of the forces.

Table 4 – Comparative combat capabilities of the Coalition forces by targets
Таблица 4 – Сравнительные боевые возможности коалиционных сил по целям
Табела 4 – Упоредне борбене способности коалиционих снага према циљевима

α	$Y_{(F,FA,A,AH)}$	$Y_{(EW,SEAD)}$	$Y_{(ADL,ADM,ADS)}$	Y_{WMD}	$Y_{(AmD,MD)}$
X_{F}	0.257	0.427	0.427	0.860	0.860
X_{B}	0.012	0.012	0.186	0.727	0.727
X_{STH}	-	-	0,800	0,600	0,600
X_{EW}	0.156	0.574	0.574	0.439	0.439
X_{FA}	0.156	0.574	0.574	0.439	0.439
X_{SEAD}	-	-	0,357	0,357	0,400
X_{AH}	0.001	0.001	0.270	0.900	0.600
X_{ADL}	0.480	0.480	-	0.480	-
X_{ADM}	0.455	0.455	-	0.455	-
X_{ADS}	0.052	-	-	-	-
X_{MD}	-	-	-	0.001	0.030
X_{ABr}	-	-	-	0.010	0.500

Table 5 – Comparative combat capability of Iraqi forces by targets I
Таблица 5 – Сравнительная боеспособность иракских сил по целям I
Табела 5 – Упоредна борбена способност ирачких снага према циљевима I

β	$X_{(F,B,FA,SEAD,AH)}$	X_{STH}	X_{EW}	$X_{(ADL,ADM)}$	X_{ADS}
Y_{F}	0.131	0.004	0.01	0.116	-
Y_{FA}	0.12	0.001	0.02	0.136	0.119
Y_{A}	0.07	-	0.052	0.472	0.702
Y_{EW}	0.07	0.07	0.052	0.2	-
Y_{SEAD}	0.07	0.07	0.052	0.2	-
Recon	0.038	-	0.038	0.05	-
Y_{AH}	0.0005	-	0.0005	0.211	0.2
Y_{ADL}	0.091	0.091	0.091	-	-
Y_{ADM}	0.327	0.027	0.327	-	-
Y_{ADS}	0.057	0.057	0.057	-	-
Y_{WMD}	-	-	-	0.0499	0.0499
Y_{ArmD}	-	-	-	-	-
Y_{MD}	-	-	-	-	-

Table 6 – Comparative combat capability of Iraqi forces by targets II
Таблица 6 – Сравнительная боеспособность иракских сил по целям II
Табела 6 – Упоредна борбена способност ирачких снага према циљевима II

β	X_{WMD}	X_{MD}	X_{ABr}
Y_F	-	-	-
Y_{FA}	0.119	0.119	0.119
Y_A	0.702	0.702	0.702
Y_{EW}	-	-	-
Y_{SEAD}	-	-	-
Y_{recon}	-	-	-
Y_{AH}	0.9	0.6	0.9
Y_{ADL}	0.091	-	-
Y_{ADM}	0.327	-	-
Y_{ADS}	-	-	-
Y_{WMD}	0.5	0.2	0.1
Y_{ArmD}	0.001	0.03	0.05
Y_{MD}	0.01	0.5	0.3

The essence of the force aggregation method (Darcom Pamphlet, 1979) is reflected in the iterative procedure by which all special elemental forces of each opponent with special combat capabilities of destroying each special element of the opponent's forces are expressed as a total measure or value of the relative strength of the forces of one and the other opponent.

Results and analysis

Finally, the validation of the model and the evaluation of the representativeness of the output results of the simulation was performed by comparing the parameters of the Operation Desert Storm (data from the real world) with the results obtained by the simulation and the operational assessment method. A computer testing of the operation model was performed, according to the available data, where certain discrepancies (errors) were taken into account. The Summary Report of Desert Storm, based on an exceptional database from the Gulf War Survey (Keaney & Cohen, 1993), served to validate the model. This was a necessary condition, by which it was possible to arrive at a relatively reliable structure and functioning of the operation, as well as relatively reliable data.

The overall estimated strength of Iraqi forces is given by characteristic periods and reflects losses throughout the campaign. The situation in January 1990 marks the period of the Operation Desert Shield, and the situation in February-March 1991 includes the situation before and after the Operation Desert Storm. For more details it is useful to consult the Survey, Chapter VII (Elliot, 1994), with the list of tasks for different combat missions, with the number of flights performed and the percentage of the total sorties performed. The total number of flights during the counterair and strategic attack as a part of the campaign was about 95,000, and during the air support and air interdiction phase of operation was about 15,000 (Engelhard, 1991). The real losses of the air forces for the both opponents were as follows (Gulf War Air Power Survey, 1993d).

The comparison of actual and modeled number of flights in different missions and the consumption of ammunition were given according to Keaney & Cohen (1993) in Tables 7 and 8. At first glance, the planned combat distribution of forces by the process of targeting and the duration of the three-day cycle allows a simple calculation in simulation. In practice, a whole series of factors in real world affect execution of tasks, from weather conditions, through the correctness of the aircraft, to the specifics mission terms, target characteristics, topography and local tactical conditions in the area of operation, etc. In the case of applying the deterministic mathematical model of force aggregation, these situations can only be expressed by a probability of execution or attrition loss coefficients. This implies that we cannot use simple calculations for the precise, daily number of combat flights and ammunition consumption because the number of possible or required actions is not symmetrical with the actually performed ones, but only probable. [3]

Some facts relevant for the objectivity of modeling should be noted:

- The Iraqi Air Force initially attempted somewhat larger air defense and fighter air support operations, then only sporadically, resulting in defections to Iran, and eventually ceased operations;
- About 140 Iraqi aircraft defected to Iran, which would probably have been destroyed if they had participated in the battle. These aircraft were never recovered by Iraq;
- In the operation model, air operations were considered by available Iraqi aircraft that could be detected on the ground or in the air. Due to methodological limitations, the model, in this case,

[3] Ammunition consumption and the number of dedicated flights performed in the model were calculated, based on an assessment in relation to the required and probable number of hits of a certain type of ammunition to destroy/neutralize the target.

simultaneously calculates the probable average expenditure of precision-guided air-to-air and air-to-ground missiles;

- The model implies no possibility that part of the forces in the conflict will be out of combat and that part of the force cannot be acted upon, e.g. ammunition and equipment in shelters;
- Some of the support missions, such as air transport, aerial refueling, reconnaissance, etc., are not shown, as they are not supported by the model.

Table 7 – Comparison of real and modeled Coalition Forces air missions
Таблица 7 – Сравнение реальных и смоделированных миссий Коалиционных сил
Табела 7 – Поређење стварних и моделованих мисија коалиционих снага

Executed missions	Real World	Model
Strategic attack and interdiction	38277	33469
Air support	6128	9943
Offensive/Defensive counterair operations	19419	18228
Suppression of enemy air defense	4326	6547
Electronic warfare	2918	
Reconnaissance	3236	-
Overall Operational support	45267	-
Overall combat	68150	68188

Table 8 – Comparison of real and modeled consumption of the Coalition air weapons
Таблица 8 – Сравнение реального и смоделированного расхода оружия Коалиции
Табела 8 – Поређење реалне и моделоване потрошње наоружања Коалиције

Type of weapons	Real world	Model
Overall munitions	228182	228908
Air to Air missiles	174	738
Air defense missiles	360	316
Unguided air bombs	210004	211067
Guided Air to Ground missiles and bombs	15372	14605
Cruise missiles	333	
Anti-radiation missiles	2039	2182
Targeting phases	14	15

The final results of the Desert Storm simulation modeling are given in the overview of the state of forces for Blue (Coalition) and Red (Iraq) and in diagrams in Figures from 1 to 4.

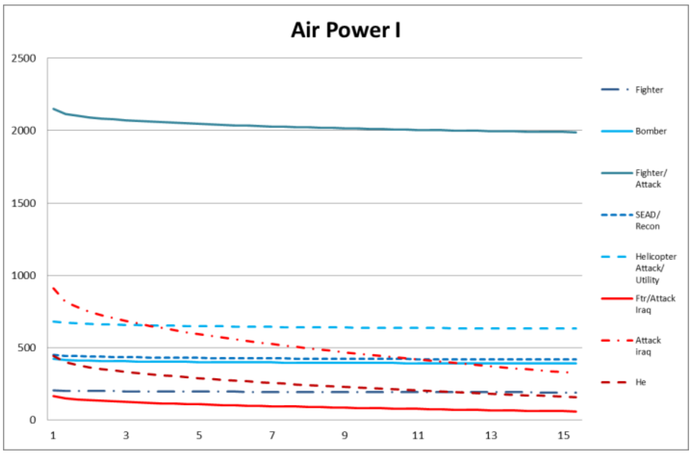


Figure 1 – Depiction of the air forces attrition process in the Operation, part 1[4]
Рис. 1 – Изображение процесса истощения ВВС в операции, часть 1
Слика 1 – Приказ процеса трошења ваздухопловних снага у операцији, 1. део

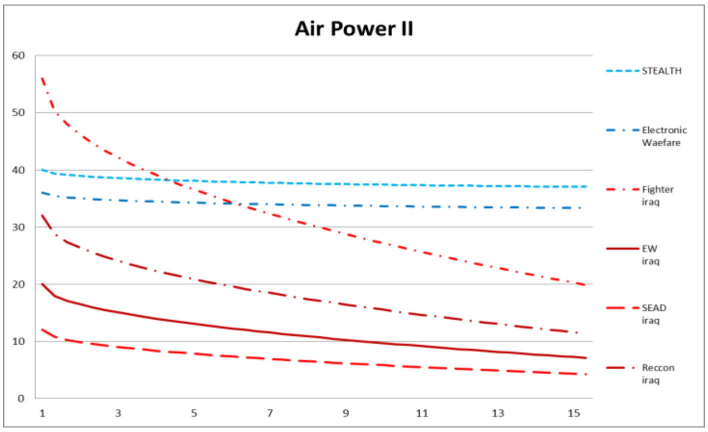


Figure 2 – Depiction of the air forces attrition process in the Operation, part 2
Рис. 2 – Изображение процесса истощения ВВС в ходе операции , часть 2.
Слика 2 – Приказ процеса трошења ваздухопловних снага у операцији, 2. део

[4] The values on the abscissa indicate the number of cycles in the targeting process, where one cycle represents 3 days. The values on the ordinate represent the numbers of elements of a combat system (the number of aircraft or elements of the tactical formation of ground units).

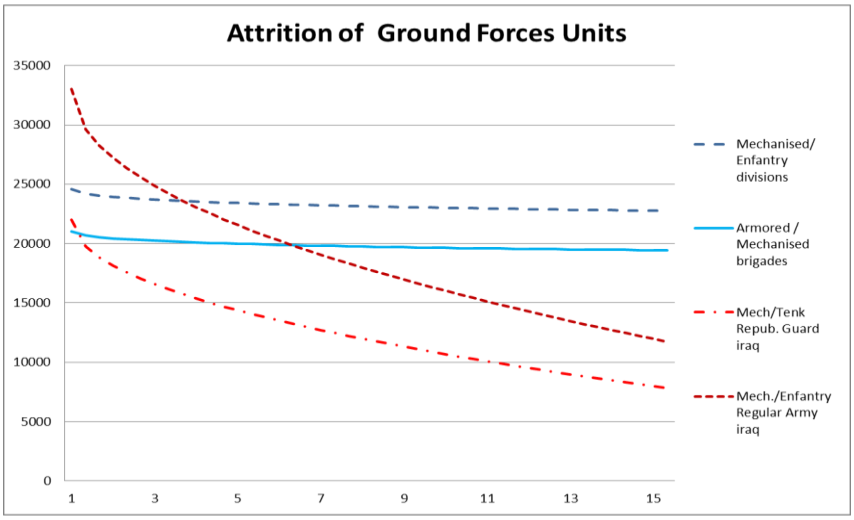


Figure 3 – Attrition process of the aggregated ground forces
Рис. 3 – Процесс истощения объединенных сухопутных войск
Слика 3 – Процес трошења агрегираних копнених снага

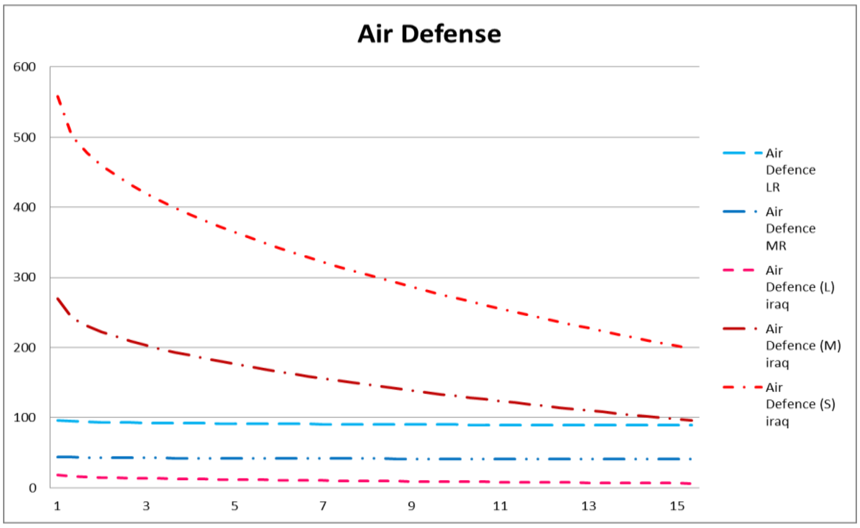


Figure 4 – Air defense attrition process
Рисунок 4 – Процесс истощения ПВО
Слика 4 – Процес исцрпљивања снага противваздухопловне одбране

An overview of the state of forces by type at the beginning and at the end of the modeled duration of the Operation Desert Storm, in a period of about 45 days, is shown in Tables 9 and 10.

Table 9 – Comparison of the Coalition and Iraqi air forces by type during the Operation
Таблица 9 – Сравнение коалиционных и иракских военно-воздушных сил по типам в ходе операции
Табела 9 – Поређење коалиционих и ирачких снага по врстама током операције

Xi	X_F	X_B	X_{STH}	X_{EW}	X_{FA}	X_{SEAD}	X_{AH}
	205	420	40	59	2150	450	681
	190	389	37	33	1989	416	630
Yj	Y_F	Y_{FA}	Y_A	Y_{EW}	Y_{SEAD}	Y_{recon}	Y_{AH}
	56	164	908	20	12	32	442
	20	58	322	7	4	11	157

Table 10 – Comparison of the Ccoalition and Iraqi air forces by type during the Operation
Таблица 10 – Сравнение коалиционных и иракских военно-воздушных сил по видам в ходе операции
Табела 10 – Поређење коалиционих и ирачких снага по врстама током операције

Xi	X_{ADL}	X_{ADM}	X_{ADS}	X_{WMD}	X_T	X_{AFV}	X_A	X_E
	96	44	-	-	7716	13160	4556	486400
	89	41	0	0	7143	12182	4217	450257
Yj	Y_{ADL}	Y_{ADM}	Y_{ADS}	Y_{WMD}	Y_T	Y_{AFV}	Y_A	Y_E
	18	270	558	110	6490	4620	4151	330000
	6	96	198	39	1480	1480	7808	11712

An analysis with a comparison of real statistical data, based on the Gulf War review (Gulf War Air Power Survey, 1993d), was performed and the modeling results were presented. Certain deviations were observed, and the results are presented comparatively as available statistical data / data obtained by the simulation process:

- operation lasted about 42 days (14 targeting cycles)/ 45 days (15 targeting cycles) in the model;
- 75 aircraft (airplanes and helicopters) of Coalition forces were shot down, and 141 were damaged / 298 in the model;
- actually destroyed planes and helicopters of Iraq were about 259, including 122 lost in air-combat, 121 defected to Iran later confiscated and about 81 destroyed on the ground/ in the model 769 planes and 285 helicopters;
- surface-to-air missile batteries lost about 115-35 / 546 in the model;
- destroyed armored forces of Iraq: 4,550 tanks and 2,840 AFV 4,139/ 2,947 in the model;

- destroyed armored forces of the Coalition 664/ 1,551 in the model;
- destroyed artillery pieces of Iraq: about 2,917/ 2,647 in the model;
- between 20,000 and 26,000 Iraqi military personnel were killed and 75,000 others were wounded/210,468 in the model; and
- Coalition forces suffered about 984 deaths / 36,143 in the model.

According to the attrition of forces diagrams, during the execution of the operation, a disproportionately higher number of losses of Iraqi forces can be clearly observed. It is also clear that the military power of the Coalition was overwhelming, resulting in a massive victory. This is a significant feature of the Operation Desert Storm. However, considering the comparison of numerical indicators (combat exhaustion), it is obvious that there are deviations, which is why the model is not fully valid and is only relatively reliable, in terms of the required precision, in the process of operational planning. It is easy to see that the losses of Iraqi air and ground forces, the losses of the Coalition forces and the number of combat sorties are not identical. The data in the model were obtained by estimating the rate of losses based on the data from the actual operation and were numerically calculated. The operational duration of the operation is only conditional because it is based on a time estimate according to the conditionality of applying Lanchester's equations (the time step must be appropriately small due to the consistency of the model).

The data differ somewhat in ammunition consumption, where there are smaller discrepancies for unguided and precision-guided weapons on surface targets. Somewhat larger deviations are observed in anti-aircraft operations and ammunition consumption. A large difference was observed in close air support (attrition and weapon consumption) and infantry casualties of both opponents.

There is an interesting observation by American experts that the assessment of the expenditure of forces in modeled combat operations from the Vietnam War to the Operation Desert Storm is constantly exaggerated and relatively wrong in relation to reality. Also, it should be noted that when checking the ATLAS model by SHAPE Headquarters, based on the data on the numerical superiority of the Allies in the war in Europe in 1940, a conclusion was reached about the very quick defeat of the Germans (Dupuy, 1997). The general conclusion is that models lose their fidelity when trying to simulate large campaigns because they cannot faithfully replicate their enormous complexity, a correlation already emphasized by Taylor (1980a). This is an essential issue in the application of computer simulations, where most military-political experts do not know the mathematical basis of the program. They cannot explain countermeasures, execution kinematics, deception, decisions by fighters and commanders in real time, changes in tactics as the campaign progresses, moral, etc. When considering the application of this method, objections to methodological inconsistency need to be emphasized, as seen in the Handbook (Darcom Pamphlet, 1979) where Howes and Thrall discuss several different methods for determining the relative weights or values, and give examples of their recommended ideal weights (Howes & Thrall, 1973). However, a bigger problem is that weights or values should be cross-structured so that the total representative strengths or equivalent combat powers can be determined on the same homogeneous scale and in terms of the same weapon (Holter, 1973). Many models only extrapolate individual force engagements in combat from scenarios versus complex ones (Berenson, 1997) which is a gross methodological error.

In this case, it is important to note that the mathematical model is deterministic and discrete, with calibration performed for certain deviations that have appeared in relation to reality but can be considered acceptable for several reasons.

The first reason is that the model processes operational actions on the battlefield and in the operational depth, according to the doctrinal principles of use, but also taking into account the specific situation in this conflict. This means that it was practically difficult to project a real combat sortie and the availability of Iraqi aircraft, air defense and other types of weapons to act as targets, due to the atypical use, because the Iraqis decided to preserve their aviation and army forces by masking them, expecting a ground operation. On the other hand, the Coalition forces avoided air-ground combat until the last 100 hours of the operation;

Secondly, actions on strategic objects, such as communications, energy, industrial and economic, or political infrastructure of Iraq, were partially taken into account, where a part of guided aerial bombs, missiles and cruise missiles were probably used;

Thirdly, given the stochastic nature of the actual process of armed struggle, certain interruptions and changes in the planned actions, caused by various causes, were sure to occur, which affected the change of action plans, increased the consumption of ammunition in reality and caused atypical use of the methodology; and

Lastly and most importantly, the force aggregation method requires a recalculation for each special phase or stage of the operation, due to the change in the operational situation, which is reflected in the operational capabilities and combat order or the strength of the forces in battle (firepower index and force value - Firepower Score).

According to formal criteria, the observed Operation Desert Storm can be viewed as a realistic system described at a higher level, while the created deterministic model is at a lower level of description and has been formally verified, in terms of the accuracy of the calculation of the given parameters. The partial validity of the model, which describes the conflict on a practical historical example from a case study, was confirmed, given that the creator of the model is methodologically allowed to determine the maximum degree of deviation. As stated, the combat was not conducted according to doctrinal principles, which would have meant an air-ground battle and the engagement of the full combat potential of both sides. In this sense, the entire campaign can be generally divided into the first part, which includes a strategic air operation: "crushing the military power of Iraq" and the second part: "an offensive air-ground operation," which expelled the Iraqi forces from Kuwait and then destroyed them. According to the formal objectives of the real operation and the results obtained, it can be said that the model is approximately satisfactory, considering the final numerical results, in terms of the large disproportion of Iraqi losses in relation to the Coalition forces and the duration of the operation.

Larger discrepancy is observed in the Coalition ground troop losses, which is a problem of force aggregation combat modeling, where it is assumed that all forces participate in operations simultaneously. It is interesting that the Coalition planners also assumed higher losses around 45,000 (Correll et al, 2021), which resulted in a change in the way of using forces and abandoning the then valid doctrinal principles of an air-ground battle. The result is the strategic use of air power in crushing Iraq's military power. When the last phase of the operation began, there was almost no ground combat, with a few exceptions.

An unsolved part of the problem of applying this model as a means of support in the process of operational planning is the possibility of optimizing the use of forces in combat - the course of action, due to the limitations of the application of the multi-criteria optimization method.

However, the real problem of the model's reality arises during the duration of the process, when operational conditions are applied and power losses lead to absurd situations. As an example, we can cite the situation of fighting forces that do not have the possibility of fighting each other, which can happen due to the percentage decrease in the power of joint units. It would be an example of a battle between naval and land forces (ships at sea, tanks in plains and infantry against modern aviation). The model would still recalculate losses even though the possibility of interaction between combat entities does not exist.

Conclusion

The created deterministic, discrete mathematical model of a strategic campaign can be used during further experimentation and consideration as a strategic planning tool, to obtain certain data, which deepens and expands knowledge, with certain limitations on reliability.

The complexity of applying the model is precisely the problem of the power aggregation method. Modeling requires iteratively repeating the aggregation process for each distinct phase of the operation. The reason for this is that, due to a change in intermediate objectives and/or methods of execution of action, there is a change in combat capabilities and the size of the forces fighting in certain regions, directions and in a certain operational environment. These changes affect the operational capabilities of the force and the coefficient of force attrition, which implies changes in the FPS and the FPI in the model. This, consequently, requires phase modeling, for each specific phase or area of the battlefield, which implies recalculation and the use of far more complex software, in order to obtain the results necessary for the planning process in real time.

For these reasons, there are certain objective limitations for the application of modeling of military operations, and especially for the optimization of the use of forces at the tactical and operational level of the battlefield. However, the model provides a relatively reliable assessment of the outcome of the operation, with conditionally adequate assessment of numerical indicators, with the above assumptions.

A special problem for the optimization of the force use model (optimal course of action) is the methodological basis of the method itself, which does not ensure the use of any of the multi-objective programming methods. This prevents practical application in the targeting process, which implies optimal planning by grouping forces with the arrangement of objects of action and the required targeted effects, which is the core of the operational planning process. The problem could eventually be solved by applying multi-attribute optimization methods, which would require the development of several scenarios with the complete process of building a combat model and simulation. However, this again would not provide a real solution - optimization and is not practical for use in operational command conditions.

The essential model is usable at the operational-strategic level, where the fight of joint units and strategic formations of the armed forces is considered. The existing model offers a highly probable assessment of the outcome of a conflict or as a means of comparing the military power of two adversaries, which is its proven value. Also, it can be useful in a rough estimation of the required funds and possible losses, but these results, especially the losses and the duration of the operation, should be taken with caution.

References

Allen, P.D. 1993. *A RAND Note: Air Combat Model Engagement and Attrition Processes High Level Design*. Santa Monica, CA, USA: RAND [online]. Available at: https://www.rand.org/content/dam/rand/pubs/notes/2008/N3566.pdf [Accessed: 19 March 2023].

Baik, S.-W. 2013. A Raid-Type War-Game Model Based on a Discrete Multi-Weapon Lanchester's Law. *Management Science and Financial Engineering,* 19(2), pp.31-36. Available at: https://doi.org/10.7737/MSFE.2013.19.2.031.

Barkdoll, T.C., Gaver, D.P., Glazebrook, K.D., Jacobs, P.A. & Posadas, S. 2002. Suppression of enemy air defenses (SEAD) as an information duel. *NRL-Naval Research Logistics*, 49(8), pp.723-742. Available at: https://doi.org/10.1002/nav.10046.

Berenson, P. 1997. Letter from Dr. Berenson, Subject: Validation. *The International TNDM Newsletter*, 1(4), p.6 [online]. Available at: http://www.dupuyinstitute.org/pdf/v1n4.pdf [Accessed: 19 March 2023].

Berkovitz, L.D. & Dresher, M. 1959. A Game-Theory Analysis of Tactical Air War. *Operations Research*, 7(5), pp.599-620. Available at: https://doi.org/10.1287/opre.7.5.599.

Bonder, S. 1970. Letter to the Editor—The Mean Lanchester Attrition Rate. *Operations Research*, 18(1), pp.179-181. Available at: https://doi.org/10.1287/opre.18.1.179.

Bulger, J.A. 1997. Air Model Historical Data Study. *The International TNDM Newsletter*, 1(4), pp.21-28 [online]. Available at: http://www.dupuyinstitute.org/pdf/v1n5.pdf [Accessed: 19 March 2023].

Correll, J.T., Reynolds, R.T., Birkey, D., Schanz, M., Deptula, D.A., Warden, J.A., Rice, D.B., Loh, J.M., Horner, C.A. & Lambeth, B.S. 2021. *Desert Storm: 30 years later, Lessons from the 1991 Air Campaign in the Persian Gulf War.* Arlington, VA, USA: The Mitchell Institute for Aerospace Studies & The Air Force Association [online]. Available at: https://mitchellaerospacepower.org/wp-content/uploads/2021/01/a2dd91_a046ea712d0e4b7fb6f7afc4483df56f.pdf [Accessed: 19 March 2023].

Coulson, S.G. 2019. Lanchester modeling of intelligence in combat. *IMA Journal of Management Mathematics,* 30(2), pp.149-164. Available at: https://doi.org/10.1093/imaman/dpx014.

-Darcom Pamphlet No.706-102. 1979. *Engineering Design Handbook: Army Weapon Systems Analysis, Part Two.* Alexandria, VA, USA: Department of the Army Headquarters Us Army Materiel Development and Readiness Command [online]. Available at: https://apps.dtic.mil/dtic/tr/fulltext/u2/a086388.pdf. [Accessed: 19 March 2023].

Deitchman, S.J. 1962. A Lanchester Model of Guerrilla Warfare. *Operations Research*, 10(6), pp.818-827. Available at: https://doi.org/10.1287/opre.10.6.818.

Dupuy, T.N. 1997. Military History and Validation of Combat Models: A Presentation at MORS Mini-Symposium on Validation, 16 Oct 1990. *The International TNDM Newsletter*, 1(4), pp.11-13 [online]. Available at: http://www.dupuyinstitute.org/pdf/v1n4.pdf [Accessed: 19 March 2023].

Engel, J.H. 1954. A Verification of Lanchester's Law. *Journal of the Operations Research Society of America*, 2(2), pp.163-171. Available at: https://www.jstor.org/stable/166602 [Accessed: 19 March 2023]

Engelhard P.J. 1991. *SSI Special Report: Desert Shield and Desert Storm, A Chronology and Troop List For the 1990-1991 Persian Gulf Crisis*. U.S. Army War College, Strategic Studies Institute [online]. Available at: https://apps.dtic.mil/sti/pdfs/ADA234743.pdf [Accessed: 19 April 2023].

Fricker, R.D. 1997. Attrition models of the Ardennes campaign. *NRL-Naval Research Logistics*, 45 (1), pp.1-22. Available at: https://doi.org/10.1002/(SICI)1520-6750(199802)45:1<1::AID-NAV1>3.0.CO;2-D.

-Gulf War Air Power Surwey. 1993a. Planning and Command and Control. In: In: Cohen, E.A. (Director) & Staff *Gulf War Air Power Survey,* Vol. I. Washington, DC, USA: United State Department of the Air Force & US. Government Printing Office [online]. Available at: https://media.defense.gov/2010/Sep/27/2001329802/-1/-1/0/AFD-100927-062.pdf [Accessed: 19 March 2023]. ISBN: 0-16-042909-9.

-Gulf War Air Power Surwey. 1993b. Operations and Effect and Effectiveness. In: Cohen, E.A. (Director) & Staff *Gulf War Air Power Survey,* Vol. II. Washington, DC, USA: United State Department of the Air Force & US. Government Printing Office [online]. Available at: https://media.defense.gov/2010/Sep/27/2001329806/-1/-1/0/AFD-100927-067.pdf [Accessed: 19 March 2023]. ISBN: 0-16-042910-2.

-Gulf War Air Power Surwey. 1993c. Weapons, Tactics, and Training and Space Operations. In: Cohen, E.A. (Director) & Staff *Gulf War Air Power Survey,* Vol. IV. Washington, DC, USA: United State Department of the Air Force & US. Government Printing Office [online]. Available at: https://media.defense.gov/2010/Sep/27/2001329817/-1/-1/0/AFD-100927-066.pdf [Accessed: 19 March 2023]. ISBN: 0-16-042927-7.

-Gulf War Air Power Surwey. 1993d. A Statistical Compendum and Chronology. In: Cohen, E.A. (Director) & Staff *Gulf War Air Power Surwey,* Vol. V. Washington, DC, USA: United State Department of the Air Force & US. Government Printing Office [online]. Available at: https://media.defense.gov/2010/Sep/27/2001329816/-1/-1/0/AFD-100927-065.pdf [Accessed: 19 March 2023]. ISBN: 0-16-042055-5.

Helmbold, R.L. 1965. Letter to the Editor—A Modification of Lanchester's Equations. *Operations Research*, 13(5), pp.857-859. Available at: https://doi.org/10.1287/opre.13.5.857.

Helmbold, R.L. & Rehm, A.S.1995. “The influence of the numerical strength of engaged forces in their casualties,” by M. Osipov (English translation of the five-part series of articles that M. Osipov published in the Russian journal Voennniy Sbornik/Military Collection). *NRL-Naval Research Logistics,* 42(3), pp.435-490. Available at: https://doi.org/10.1002/1520-6750(199504)42:3<435::AID-NAV3220420308>3.0.CO;2-2.

Holter, W.H. 1973. *A Method for Determining Individual and Combined Weapons Effectiveness Measures Utilizing the Results of a High-Resolution Combat Simulation Model*. McLean, VA, USA: General Research Corp Mclean [online]. Available at: https://apps.dtic.mil/sti/citations/ADP000609 [Accessed: 19 March 2023].

Howes, D.R. & Thrall, R.M. 1973. A theory of ideal linear weights for heterogeneous combat forces. *Naval Research Logistics Quarterly,* 20(4), pp.645-659. Available at: https://doi.org/10.1002/nav.3800200406.

Hsiao, H. & Guu, S.-M. 2004. A Differential Game for Air-Land Combat Operations, Department of Industrial Engineering and Management. *Semantic Scholar* [online]. Available at: https://pdfs.semanticscholar.org/6d7f/b13da1da57a9b5d3803c08941ccdb929b61b.pdf [Accessed: 19 March 2023].

Isaacs, R. 1965. *Differential Games*. New York: John Wiley & Sons. ISBN: 0-486-40682-2.

Keaney, T.A. & Cohen, E.A. 1993. *Gulf War: Air Power Survey, Summary Report.* Washington, DC, USA: United State Department of the Air Force & US. Government Printing Office [online]. Available at: https://media.defense.gov/2010/Sep/27/2001329801/-1/-1/0/AFD-100927-061.pdf [Accessed: 19 March 2023]. ISBN: 0-16-041950-6.

Kress, M. 2020. Lanchester Models for Irregular Warfare. *Mathematics*, 8(5), art. number:737. Available at: https://doi.org/10.3390/math8050737.

Lanchester, F.W. 1916. *Aircraft in Warfare: The Dawn of the Fourth Arm*. London, UK: Constable and Company Limited [online]. Available at: https://archive.org/details/aircraftinwarfar00lancrich/page/30/mode/1up?ref=ol&view=theater [Accessed: 19 March 2023].

Lucas, T.W. & Turkes, T. 2004. Fitting Lanchester Equations to the Battles of Kursk and Ardennes. *NRL-Naval Research Logistics*, 51(1), pp.95-116. Available at: https://doi.org/10.1002/nav.10101.

MacKay, N.J. 2006. Lanchester combat models. *arXiv:math/0606300 [math.HO]*. Available at: https://doi.org/10.48550/arXiv.math/0606300.

Protopopescu, V., Santoro, R.T., Cox, R.L. & Rusu, P. 1990. Technical Report: Combat modeling with partial differential equations: The bidimensional case. *OSTI.GOV U.S. Department of Energy Office of Scientific and Technical Information* [online]. Available at: https://doi.org/10.2172/5233113.

Taylor, J.G. 1980a. *Lanchester-Type Models of Warfare. Volume I*. Monterey, CA, USA: Naval Postgraduate School [online]. Available at: https://apps.dtic.mil/sti/citations/ADA090842 [Accessed: 19 March 2023].

Taylor, J.G. 1980b. *Lanchester-Type Models of Warfare, Volume II.* Monterey, CA, USA: Calhoun-The NPS Institutional Archive DSpace Repository [online]. Available at: https://calhoun.nps.edu/handle/10945/40200 [Accessed: 19 March 2023].

Washburn, A. 2000. *Lanchester Systems*. Monterey, CA, USA: Naval Postgraduate School [online]. Available at: https://apps.dtic.mil/sti/pdfs/ADA383409.pdf [Accessed: 19 March 2023].

Washburn, A., Caldwell, B., Hartman, J., Parry, S. & Youngren, M. 2022. *Aggregated Combat Models.* Monterey, CA, USA: Naval Postgraduate School, Operations Research Department [online]. Available at: http://faculty.nps.edu/awashburn/ . [Accessed: 19 March 2023].

Washburn, A. & Kress, M, A. 2009, *Combat Modeling*. New York, NY: Springer, pp. 100-105. Available at: https://doi.org/10.1007/978-1-4419-0790-5.

Моделирование боевых действий

Младен С. Костич, **корреспондент**, *Ака* Д. Йованович, *Митар* В. Ковач

Университет Эдуконс, факультет управления проектами и инновациями, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 27.47.00 Математическая кибернетика,
27.47.19 Расследование операций,
28.17.31 Моделирование процессов управления
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Целью данного *исследования являются проверка и оценка приближенного метода модели стратегических боевых действий объединенных сил, основанной на уравнениях Ланчестера.*

Методы: На примере известной операции «Буря в пустыне» были собраны необходимые данные о боевых возможностях и численности противника, оперативной обстановке, доктринальных принципах и способах применения сил в боевых задачах. Полученные данные обрабатывались методом агрегирования сил, преобразуя силы разнородного состава в однородные. Моделирование боевых действий проводилось с помощью метода дифференциальных уравнений Ланчестера.

Результаты: В ходе исследования была п*одтверждена частичная валидность модели, описывающей вооруженный конфликт, на практическом историческом примере* анализированного случая *с учетом влияния параметров исхода конфликта, соотношения потерь, расхода боеприпасов и количества выполненных воздушных операций.*

Выводы: В результате исследования были выявлены объективные ограничения в применении моделирования боевых действий, оптимизации применения сил на тактическом и оперативном уровнях. Ценность данного метода заключается в возможности надежной стратегической оценки военной мощи противника на стратегическом уровне.

Ключевые слова: боевые действия воздух-земля, истощение, модель объединенных сил.

Моделовање борбених операција

Младен С. Костић, **аутор за преписку**, *Аца* Д. Јовановић, *Митар* В. Ковач

Универзитет Едуконс, Факултет за пројектни и иновациони менаџмент, Београд, Република Србија

ОБЛАСТ: математика, војне науке
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Циљ истраживања је провера и процена апроксимативне методе модела стратегијских борбених дејстава агрегатних снага, базираним на Ланчестеровим једначинама.

Методе: Студијом случаја познате операције „Пустињска олуја" прикупљени су потребни подаци о борбеним способностима и снази непријатеља, оперативним факторима, доктринарним принципима и начину употребе снага у борби. Добијени подаци су обрађени методом агрегације сила, трансформишући снаге хетерогеног састава у хомогене. Моделовање битке је спроведено методом диференцијалних Ланчестерових једначина.

Резултати: Потврђена је делимична валидност модела који описује сукоб на практичном историјском примеру из студије случаја, узимајући у обзир утицај параметара исхода сукоба, односа губитака, потрошње убојних средстава и броја изведених ваздухопловних мисија.

Закључак: Постоје објективна ограничења у примени моделовања војних операција, и оптимизацији употребе снага на тактичком и оперативном нивоу. Вредност овог метода јесте могућност поуздане стратешке процене војне моћи противника на стратешком нивоу.

Кључне речи: ваздухопловно-копнене борбене операције, исцрпљивање, модел агрегатних снага.

Paper received on / Дата получения работы / Датум пријема чланка: 20.03.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 06.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 08.06.2023.

Design of a cosine pulse transceiver operating in the discrete-time domain

Stevan M. Berber
The University of Auckland,
Department of Electrical, Computer and Software Engineering,
Auckland, New Zealand,
e-mail: s.berber@auckland.ac.nz,
ORCID ID: https://orcid.org/0000-0002-2432-3088

DOI: 10.5937/vojtehg71-43566; https://doi.org/10.5937/vojtehg71-43566

FIELD: electrical engineering, telecommunications
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The paper presents the theory and the design issues of a transceiver for a discrete-time cosine pulse transmission. The operation of the transceiver and all signals are analyzed in both time and frequency domains.

Methods: The detailed theoretical models of the transmitter and the receiver are presented based on their block schematics expressed in terms of mathematical operators. The transceiver blocks are simulated and the results of their simulation are presented and compared with the theoretical results.

Results: Discrete-time signals at the input and the output of each transceiver block are derived in the mathematical form and presented in the time and frequency domain. A transceiver simulator is developed in Matlab. The simulation results confirmed the theoretical findings.

Conclusion: The results of this work contribute to the theoretical modeling and design of modern transceivers that can be used for discrete-time cosine pulse transmission.

Keywords: transceiver design, discrete cosine pulse, pulse transceiver, transceiver mathematical modeling, filtering, transceiver simulation.

Introduction

Designs of communication transmitters and receivers are based on the presentation of signals in the continuous-time domain, i.e., in their analysis and synthesis, signals are presented as continuous functions of time. Related communication systems, composed of these devices, are known under the name of digital communication systems (Haykin, 2014; Proakis, 2001). Due to the development of advanced digital technology, signals of modern communication systems are represented by discrete-time functions and are known under the name discrete communication systems (Rice, 2009; Berber, 2021; Abramowitz & Stegun, 1972).

Designs of modern transmitters and receivers are implemented in digital technology, primarily on FPGA and DSP platforms. Using these technologies, the signal processing operations inside both baseband and intermediate frequency transceiver blocks are implemented using the signal presentation in the discrete-time domain. These designs became possible due to the advances in the mathematical theory of discrete-time signal processing, and, in particular, due to the development of the mathematical theory of discrete-time deterministic and stochastic processes (Manolakis et al, 2005; Berber, 2009).

This paper presents the theoretical base of a discrete communication system assuming that the modulating signal is a cosine discrete-time pulse, including the issues of mathematical modeling and design of a discrete communication system composed of a transmitter, a transmission channel, and a receiver. The signals are expressed as functions of the discrete-time variables. To distinguish discrete systems from digital systems, we named systems operating in the continuous time domain digital systems, and systems operating in the discrete-time domain we named *discrete systems* (Miao, 2007; Benvenuto et al, 2007; Berber, 2021).

In particular, the structure and the operation of the receiver having a low-pass filter at the receiver side are analyzed. The presented system structures are expressed in terms of mathematical operators and their operations are explained using exact mathematical expressions. The designed transceiver is simulated to confirm the presented mathematical model (Ingle & Proakis, 2012; Nguyen et al, 2015).

Based on the time and frequency domain presentation of the transceiver signals, and the power and energy spectral densities calculations, the power and the energies of the related signals are calculated assuming the ideal transmission of the signals in the noiseless channel. These calculations allowed a clear understanding of the transceiver operation and the estimations of possible losses in signal powers that were caused by the signal processing in the transceiver.

The presented theory of modern discrete communication systems design is of vital importance for researchers, practicing engineers, and designers of transceiver devices because the design of these devices is impossible without a deep understanding of the theoretical principles and concepts related to their operation in the discrete-time domain (Rice, 2009; Berber, 2021).

Discrete-time communication system structure and operation

A block schematic of a discrete communication system under consideration, which includes its basic block presented in the form of mathematical operators, is shown in Figure 1. The system consists of a transmitter, a band-pass noise generator, and a receiver. At the input of the transmitter there is a low frequency (LF) discrete rectangular pulse $p(n)$ that modulates an LF cosine signal $s_m(n)$ to produce an LF cosine pulse $m(n)$. This cosine pulse modulates the carrier $s_c(n)$. The obtained band-pass modulated signal $s(n)$ is generated at the output of the transmitter.

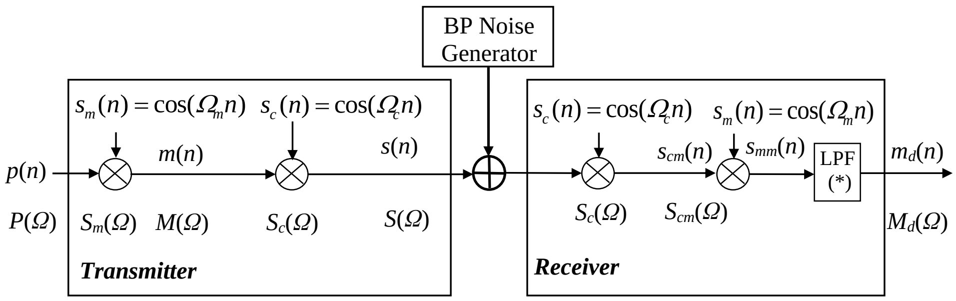


Figure 1 – Block schematic of a communication system operating in the discrete-time domain
Рис. 1 – Структурная схема системы связи, работающей в области дискретного времени
Слика 1 – Блок-шема комуникационог система који ради у домену дискретног времена

The coherent receiver will demodulate the received band-pass (BP) signal using a low-pass filter (LPF) and generate an estimate of the cosine pulse or the rectangular pulse transmitted. Firstly, the modulated signal $s(n)$ is multiplied by the carrier $s_c(n)$ to obtain the demodulated cosine pulse $s_{cm}(n)$. Then, the cosine pulse is multiplied by the LF cosine signal $s_m(n)$ to obtain a signal $s_{mm}(n)$ that contains the rectangular pulse that can be extracted by the low-pass filter (LPF). In the case of the system simulation, a band-pass noise generator should be used to investigate the operation of the system in real conditions. Because the system operates with discrete-time signals, the noise generator needs to generate a BP discrete-time noise that will be added to the modulated discrete-time signal.

Transmitter operation

We will generate the discrete-time cosine pulse and then modulate the carrier with that cosine pulse. The block schematic of the transmitter is presented in Figure 1. The generated pulse can be considered an LF cosine pulse. However, our question is how to generate the band-pass sinusoidal pulse with the modulating signal that is this LF cosine signal. For that purpose, as we expect, the carrier frequency should be much higher than the bandwidth of the LF cosine pulse. Let us assume, for the sake of explanation and presentation, that the carrier frequency is 10 times higher than the middle frequency of the LF cosine pulse.

To generate this modulated pulse, we need to multiply the LF cosine pulse with the carrier, as shown in Figure 1. The carrier frequency is 10 times higher than the frequency of the cosine pulse, i.e., $f_c = 10f_m$. Suppose the minimum number of samples in one period of the carrier is $N_c = 4$. Therefore, the number of samples N of the rectangular pulse $p(n)$ (for 2 oscillations of the LF cosine pulse and 20 oscillations of the carrier and the number of samples N_m in one period of the LF cosine signal) needs to be calculated to accommodate the 10 times higher frequency of the carrier, i.e.,

$$N = 10 \cdot 2 \cdot N_c = 20 \cdot 4 = 80\,. \qquad (1)$$

The number of samples inside one period of the LF cosine pulse now is calculated to be $N_m = N/2 = 40$. Therefore, to perform the multiplication of the rectangular pulse by the LF cosine signal and then modulate the carrier, the number of their samples should be 80. The mathematical expressions and related wave shapes of the transmitter signals will be presented in the following analysis. For the calculated values of the discrete signals, we can analyze their properties in the time and frequency domain at each block of the transceiver.

The rectangular pulse presentation in the time and frequency domain. Based on the calculated number of samples inside the processed signals, the graphs of the discrete-time (dt) rectangular pulse $p(n)$ in the discrete-time domain are presented in Figure 2. The signal is expressed in terms of the Kronecker delta functions as a convolution of the signal and the delta functions. i.e.,

$$p(n) = \sum_{k=0}^{N-1} m(k)\delta(n\text{-}k) = \begin{Bmatrix} A & 0 \le n \le N-1 \\ 0 & otherwise \end{Bmatrix} = \begin{Bmatrix} A & 0 \le n \le 79 \\ 0 & otherwise \end{Bmatrix}. \qquad (2)$$

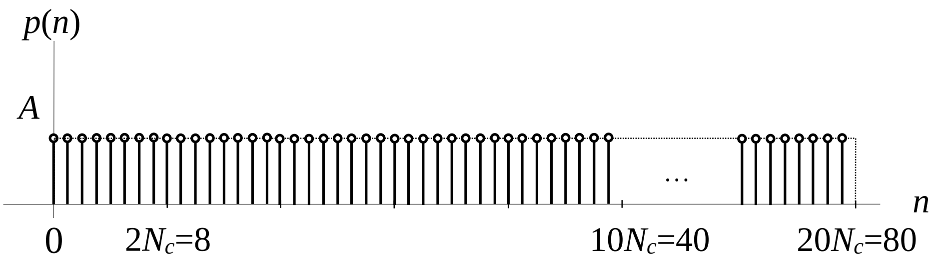


Figure 2 − Discrete-time modulating signal for N = 80 and A = 2
Рис. 2 – Модулирующий сигнал с дискретным временем при N = 80 и A = 2
Слика 2 – Модулишући сигнал дискретног времена за N = 80 и A = 2

It is to note that the discrete-time pulse values are defined for each whole number n and have no values in the intervals between neighboring numbers. We can say that the signal values do not exist in these intervals, even though these intervals are used to process the discrete signal values. The related magnitude and phase spectral densities can be obtained from the DTFT of the dt rectangular pulse which is defined as

$$P(\Omega) = \sum_{n=-\infty}^{\infty} p(n) e^{-j\Omega n} = \sum_{n=0}^{n=(N-1)} A e^{-j\Omega n}$$

$$= \left. \begin{cases} AN & \Omega = \pm 2k\pi, k = 0, 1, 2, 3, ... \\ Ae^{-j\Omega(N-1)/2} \dfrac{\sin(\Omega N/2)}{\sin(\Omega/2)} & \text{otherwise} \end{cases} \right|_{N=80}, \quad (3)$$

and is to be calculated for N = 80. The magnitude spectral density can be expressed as

$$P(\Omega) = \begin{cases} |AN| & \Omega = \pm 2k\pi, k = 0, 1, 2, 3, ... \\ \left| A \dfrac{\sin(\Omega N/2)}{\sin(\Omega/2)} \right| & \textit{otherwise} \end{cases}, \quad (4)$$

which is graphically presented in Figure 3 for the defined duration of the pulse N = 80 and the amplitude A = 2. The zeros in the magnitude spectrum occur for the condition expressed as $\sin(\Omega_0 N/2) = 0$, i.e., for $\Omega_0 N/2 = k\pi$ or k = 1, 2, …, N-1. For N = 80, we may have $\Omega_0 = \pm 2k\pi/N = \pm k\pi/40$, and k = 1, 2, …, 79. The phase discontinuities of π radians occur at the same frequencies. The related magnitude spectral density is shown in Figure 3.

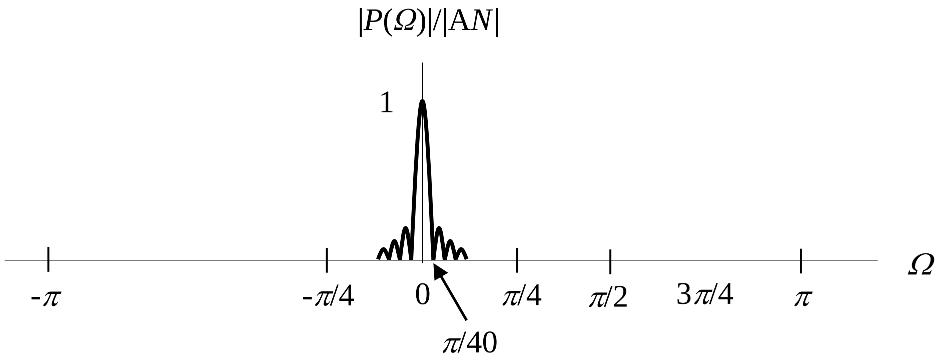


Figure 3 – Magnitude spectral density of the rectangular pulse
Рис. 3 – Спектральная плотность колебаний правоугольного импульса
Слика 3 – Спектрална густина магнитуде правоугаоног пулса

The first zero crossing occurs at the frequency $\pi/40$. The magnitude value for zero frequency is normalized by $|AN|$ to be one. We can calculate the power and energy of the pulse in the time domain for the values of the signal that are different from zero as

$$P_p = \frac{1}{N}\sum_{n=0}^{N-1} p^2(n) = \frac{1}{80}\sum_{n=0}^{n=79} A^2 = \frac{1}{80}80A^2 = A^2, \tag{5}$$

$$E_p = P_p \cdot N = \sum_{n=0}^{N-1} p^2(n) = \sum_{n=0}^{n=79} A^2 = NA^2 = 80A^2. \tag{6}$$

On the other hand, the energy spectral density (ESD) of the pulse is defined as the magnitude spectral density square and expressed as

$$E_p(\Omega) = |P(\Omega)|^2 = \left| A\frac{\sin(\Omega N/2)}{\sin(\Omega/2)} \right|^2. \tag{7}$$

In the frequency domain, the energy of the pulse is calculated as an integral of the ESD in this way (Integral calculator, 2023)

$$E_p = \frac{1}{2\pi}\int_{-\pi}^{\pi} |P(\Omega)|^2 \, d\Omega = \frac{A^2}{2\pi}\int_{-\pi}^{\pi} \left\| \frac{\sin(\Omega N/2)}{\sin(\Omega/2)} \right\|^2 d\Omega = \frac{A^2}{2\pi}160\pi = NA^2 = 80A^2. \tag{8}$$

The ESD can be calculated also as the DTFT of the autocorrelation function of the discrete rectangular pulse (Berber, 2019, 2021).

The LF cosine signal in the time and frequency domain. The LF cosine signal has N_m = 40 samples per oscillation, which can be understood as a subcarrier in the system. Therefore, its frequency is $\Omega_m = 2\pi f_m / f_s = 2\pi / N_m = \pi / 20$. This signal in the time domain is

$$s_m(n) = \cos\Omega_m n = \cos 2\pi n / N_m = \cos\pi n / 20 \,, \quad (9)$$

which is shown in a graphical form in Figure 4a).

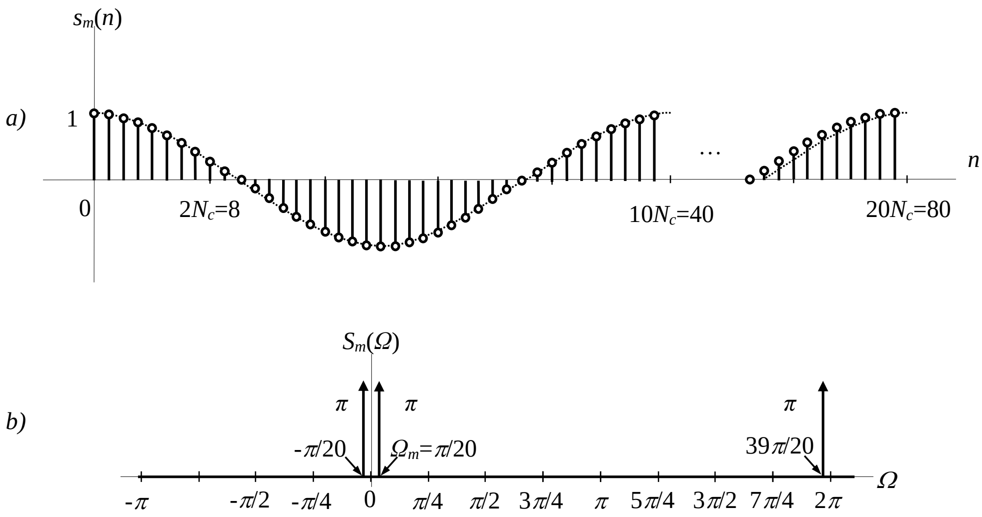


Figure 4 − a) Waveshape of the LF sinusoid signal, b) related amplitude spectral density
Рис. 4 – а) Форма волны низкочастотного синусоидального сигнала, б) соответствующая амплитудная спектральная плотность
Слика 4 – а) Таласни облик НФ синусоидалног сигнала, б) односна спектрална густина амплитуде

The signal in the frequency domain can be directly found for any N_m simply applying Euler's formula on the time domain as follows

$$s_m(n) = \frac{1}{2}[e^{j2\pi n/N_m} + e^{j2\pi n(N_m-1)/N_m}] = \frac{1}{2}(e^{j\pi n/20} + e^{j\pi n 39/20}) \,, \quad (10)$$

or the amplitude spectral density expressed as

$$S_m(\Omega) = \sum_{k=\pm1} \frac{2\pi}{2}\delta(\Omega + k\cdot\Omega_m) = \pi\delta(\Omega+\Omega_m) + \pi\delta(\Omega-\Omega_m) \,, \quad (11)$$

which is a periodic function of the continuous frequency Ω with the period of 2π, as presented in Figure 4b). This spectrum can be represented by a periodic stream of the Dirac delta functions (Papoulis & Pillai, 2002) weighting π at periodic frequencies and zeros everywhere else.

The power of the signal in the time domain is calculated as

$$P_{sm} = \frac{1}{N_m}\sum_{n=0}^{N_m-1}\cos^2(\Omega_m n) = \frac{1}{40}\sum_{n=0}^{39}\cos^2(\pi n/2) = \frac{1}{40}\sum_{n=0}^{39}\frac{1}{2} = \frac{1}{2}. \quad (12)$$

This is a power signal (Cavicchi, 2007; Berber, 2021). Therefore, its average power is to be calculated in the infinite interval, according to this expression

$$P_{sm} = \lim_{a\to\infty}\frac{1}{2a}\sum_{n=-a}^{a}\cos^2(\Omega_m n) = \lim_{a\to\infty}\frac{1}{2a}\sum_{n=-a}^{a}\frac{1}{2}(1+\cos\pi n/2) = \lim_{a\to\infty}\frac{1}{2a}\frac{2a}{2} = \frac{1}{2}. \quad (13)$$

Because this signal in the frequency domain is a periodic function of the continuous frequency Ω with a period of 2π, it can be represented by a periodic stream of the Dirac delta functions, as presented in Figure 4b). The energy of the signal is

$$E_{sm} = \frac{1}{2\pi}\int_{-\infty}^{\infty}|S_m^2(\Omega)|\,d\Omega = \frac{1}{2\pi}\int_{-\pi}^{\pi}\left(\sum_{k=\pm1}\frac{2\pi}{2}\delta(\Omega+k\Omega_m)\right)^2 d\Omega$$

$$= \frac{\pi}{2}\int_{-\pi}^{\pi}\left(\delta^2(\Omega+\Omega_m)+2\delta(\Omega+\Omega_m)\delta(\Omega-\Omega_m)+\delta^2(\Omega-\Omega_m)\right)d\Omega. \quad (14)$$

$$\to\infty+0+\infty\to\infty$$

The infinite energy value can be confirmed by its calculation in the time domain as

$$E_{sm} = \lim_{a\to\infty}\sum_{n=-a}^{a}\cos^2(\Omega_m n) = \lim_{a\to\infty}\sum_{n=-a}^{a}\frac{1}{2}(1+\cos\pi n/2) = \lim_{a\to\infty}\frac{2a}{2} = \infty. \quad (15)$$

The LF cosine pulse in the time and frequency domain. The cosine pulse $m(n)$ is obtained by multiplying the $s_m(n)$ shown in Figure 1 by the rectangular pulse $p(n)$. This is again a cosine function. However, it is not a periodic function as it was the LF cosine signal $s_m(n)$. Consequently, it will not be expressed in the frequency domain in terms of the Dirac delta functions. Instead of one spectral component, the spectrum of the cosine pulse will have a bandwidth around the frequency of the periodic cosine signal. The cosine pulse can be expressed in the time domain as

$$m(n) = p(n)s_m(n) = \begin{cases} A\cos\Omega_m n & 0 \le n \le N-1 \\ 0 & otherwise \end{cases}$$
$$= \begin{cases} A\cos\pi n/20 & 0 \le n \le 79 \\ 0 & otherwise \end{cases}, \qquad (16)$$

and, based on the modulation theorem, in the frequency domain as

$$M(\Omega) = FT\{p(n)\cos\Omega_m n\} = \frac{1}{2}[P(\Omega-\Omega_m) + P(\Omega+\Omega_m)], \qquad (17)$$

where its shifted components are expressed as

$$\frac{1}{2}P(\Omega \pm \Omega_m) = \begin{cases} AN/2 & \Omega \pm \Omega_m = \mp 2k\pi, k = 0, 1, ... \\ \frac{A}{2}e^{-j(\Omega\pm\Omega_m)(N-1)/2}\frac{\sin((\Omega\pm\Omega_m)N/2)}{\sin((\Omega\pm\Omega_m)/2)} & \text{otherwise} \end{cases}$$

The cosine pulse and the related magnitude spectral density are presented in Figure 5.

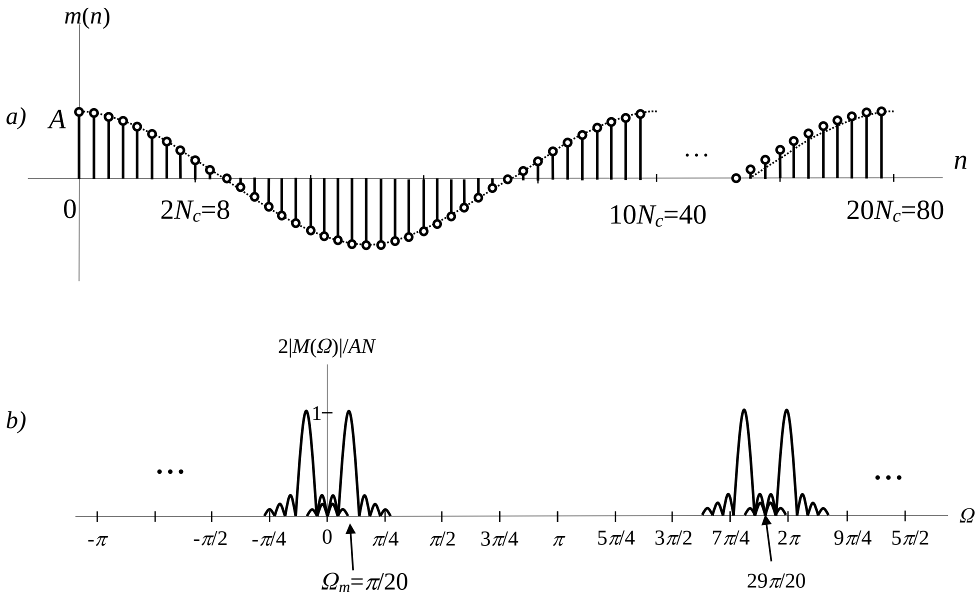


Figure 5 – a) Pulse in the time domain, b) Magnitude spectral density of the pulse
Рис. 5 – а) Форма импульса во временной области б) спектральная плотность амплитуды импульса
Слика 5 – а) Таласни облик пулса у временском домену, б) спектрална густина магнитуде пулса

The power and the energy of the cosine LF pulse are

$$P_m = \frac{1}{N}\sum_{n=0}^{N-1} A^2 \cos^2(\Omega_m n) = \frac{1}{80}\sum_{n=0}^{n=79} \frac{1}{2} A^2 (1+\cos \pi n) = \frac{A^2}{80}\sum_{n=0}^{n=79} \frac{1}{2} = \frac{A^2}{2}\ , \qquad (18)$$

$$E_m = NP_m = \sum_{n=0}^{N-1} A^2 \cos^2(\Omega_m n) = 40A^2\ . \qquad (19)$$

The amplitude spectral density is a periodic function of continuous frequency with the period of 2π as presented in Figure 5b). The signal is an energy signal, and its energy can be calculated from the energy spectral density (Integral calculator, 2023) as

$$\begin{aligned} E_m &= \frac{1}{2\pi}\int_{-\pi}^{\pi} \left|M\left(\Omega\right)\right|^2 d\Omega = \frac{1}{8\pi}\int_{-\pi}^{\pi} \left|[P(\Omega-\Omega_m) + P(\Omega+\Omega_m)\right|^2 d\Omega \\ &= \frac{A^2}{8\pi} 2\cdot 160\pi = 40A^2 \end{aligned}\ . \qquad (20)$$

The carrier in the time and frequency domain. For the defined frequency, the carrier of a unit amplitude is expressed in the discrete-time domain as

$$s_c(n) = \cos \Omega_c n = \cos 2\pi n / N_c = \cos \pi n / 2 \qquad (21)$$

as presented in Figure 6a). The carrier in the frequency domain can be directly found, for the number of samples $N_c = 4$ in one period of the carrier, by simply applying Euler's formula on the time domain expression of the signal and we may have

$$S_c\left(\Omega\right) = \sum_{k=\pm 1} \frac{2\pi}{2} \delta(\Omega + k\cdot\Omega_c) = \pi\delta(\Omega+\Omega_c) + \pi\delta(\Omega-\Omega_c)\ , \qquad (22)$$

which is a periodic function of frequency with the period of 2π, as presented in Figure 6b). Because this signal is a periodic function of the continuous frequency Ω with a period of 2π, it is represented by a periodic stream of the Dirac delta functions (Papoulis & Pillai, 2002), as presented in Figure 6b).

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2023, Vol. 71, Issue 3

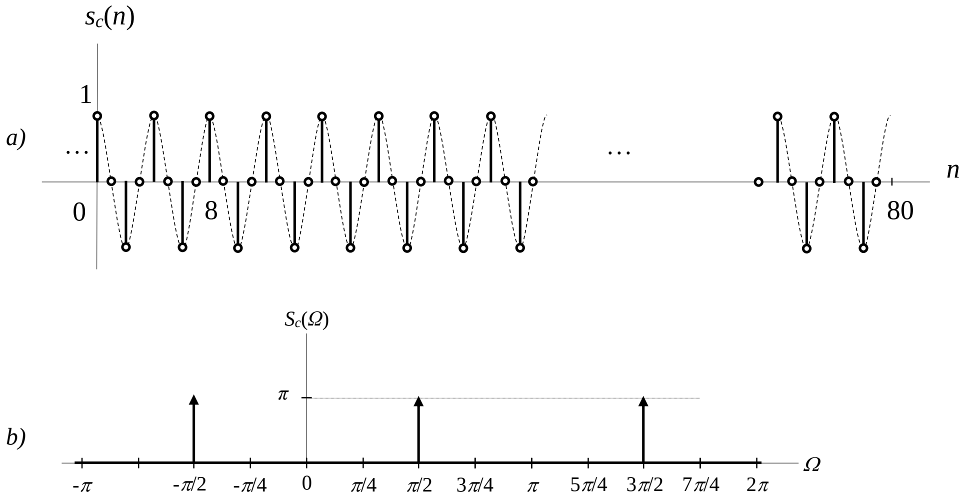


Figure 6 – a) Carrier in the time domain, b) Magnitude spectral density of the carrier
Рис. 6 – а) *Несущая волна во временной области, б) спектральная плотность колебаний несущей волны*
Слика 6 – а) Носилац у временском домену, б) спектрална густина амплитуде носиоца

The modulated signal in the time and frequency domain. The modulated signal $s(n)$ is obtained by multiplying the LF cosine pulse $m(n)$ by the carrier $s_c(n)$. The LF signal $m(n)$ is obtained by multiplying the signals $s_m(n)$ by the rectangular pulse $p(n)$, as shown in Figure 5a). Therefore, the modulated signal in the time domain is expressed as

$$s(n) = m(n) \cdot s_c(n) = p(n) s_m(n) \cdot \cos \Omega_c n \, , \tag{23}$$

and presented in Figure 7a). By applying the modulation property of DTFT, we may get the amplitude spectral density of that signal as

$$\begin{aligned} S(\Omega) &= FT\{m(n)\cos\Omega_c n\} = \frac{1}{2} FT\left\{m(n)(e^{j\Omega_c n} + e^{-j\Omega_c n})\right\} \\ &= \frac{1}{2}[M(\Omega - \Omega_c) + M(\Omega + \Omega_c)] \end{aligned} \, . \tag{24}$$

We can find its shifted components in (24) and express them as

$$\frac{1}{2}M\left(\Omega \pm \Omega_c\right) = \frac{A}{2}e^{-j(\Omega-\Omega_c)(N-1)/2}\frac{\sin\left((\Omega \pm \Omega_c)N/2\right)}{\sin\left((\Omega \pm \Omega_c)/2\right)}$$

$$= \begin{cases} AN/2 & \Omega \pm \Omega_c = \mp 2k\pi, k = 0, 1, 2, 3, \ldots \\ \dfrac{A}{2}e^{-j(\Omega \pm \Omega_c)(N-1)/2}\dfrac{\sin\left((\Omega \pm \Omega_c)N/2\right)}{\sin\left((\Omega \pm \Omega_c)/2\right)} & otherwise \end{cases},$$

where N = 80 for our case. Then, based on expression (17) for the amplitude spectral density of $m(n)$, the magnitude spectral density of the modulated signal (24) finally is

$$\begin{aligned} S(\Omega) = &\ \frac{1}{4}[P(\Omega - \Omega_c - \Omega_m) + P(\Omega - \Omega_c + \Omega_m)] \\ &+ \frac{1}{4}[P(\Omega + \Omega_c - \Omega_m) + P(\Omega + \Omega_c + \Omega_m)] \end{aligned}. \quad (25)$$

For the defined values of frequency $\Omega_m = \pi/20$ and $\Omega_c = \pi/2$, the magnitude spectral density of the modulated signal is presented in Figure 7b).

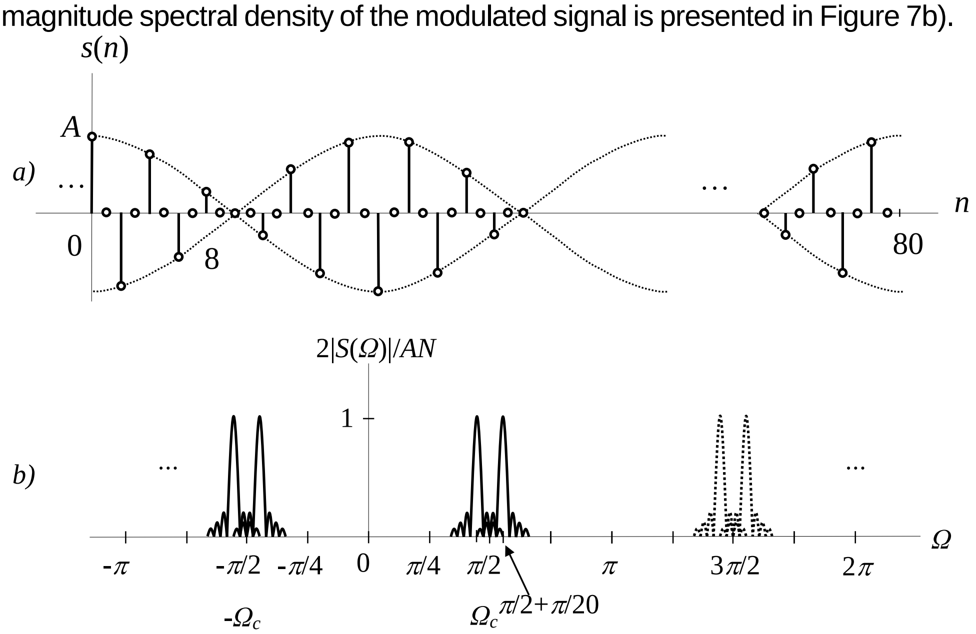


Figure 7 – a) Modulated signal in the time domain, and b) in the frequency domain
Рис. 7 – а) Модулированный сигнал во временной области и б) в частотной области
Слика 7 – а) Модулисани сигнал у временском домену, и б) у фреквенцијском домену

The magnitude spectrum is a periodic function with a period of 2π. The two-sided spectrum of the signal can be investigated inside the bandwidth around the carrier frequency of $\pi/2$.

The power of the modulated signal can be calculated in the time domain as

$$P_s = \frac{1}{N}\sum_{n=0}^{N-1} s^2(n) = \frac{1}{N}\sum_{n=0}^{N-1} p^2(n)\cos^2(\Omega_m n)\cdot\cos^2 \Omega_c n$$
$$= \frac{A^2}{320}\sum_{n=0}^{n=79}(1+\cos 2\Omega_m n)\cdot(1+\cos 2\Omega_c n) = \frac{A^2}{320}\sum_{n=0}^{n=79} 1 = \frac{A^2}{4} \tag{26}$$

The energy of the signal, based on solution (20), is

$$E_s = P_s N = \frac{1}{2\pi}\int_{-\pi}^{\pi}\left|S(\Omega)\right|^2 d\Omega$$
$$= \frac{A^2}{4}\frac{1}{2\pi}\int_{-\pi}^{\pi}\left|[M(\Omega-\Omega_c)+M(\Omega+\Omega_c)\right|^2 d\Omega = \frac{A^2}{4}(40+40) = 20A^2 \quad , (27)$$

which can be calculated as shown before. From the energy expression, it is easy to find the power of the signal and vice versa.

Simulation of the transmitter operation

We performed a simulation in Matlab of the transmitter presented in Figure 1 (Ingle & Proakis, 2012).

The signals are generated in the time and frequency domain and presented in graphical forms.

The modulating signal obtained by simulation in the time and frequency domain is presented in Figure 8.

They are equivalent to the signals that have been obtained by calculations and presented in Figures 2 and 3, respectively.

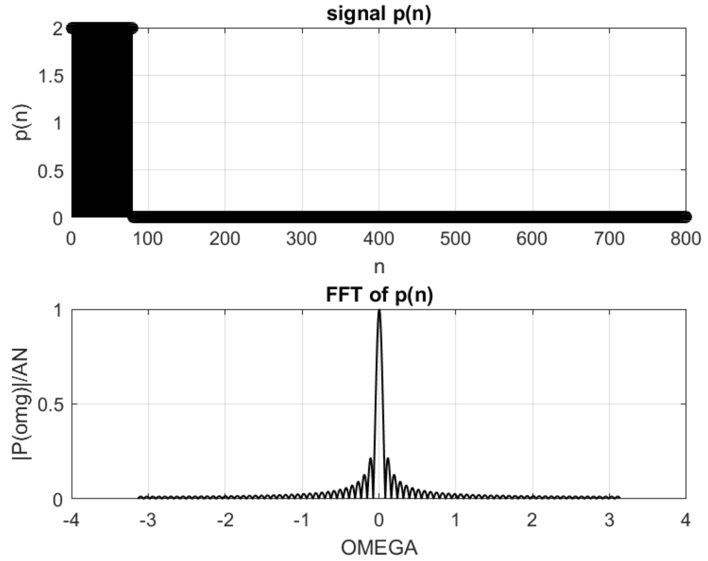


Figure 8 – Modulating signal in the time and frequency domain
Рис. 8 – Модулирующий сигнал во временной и частотной областях
Слика 8 – Модулишући сигнал у временском и фреквенцијском домену

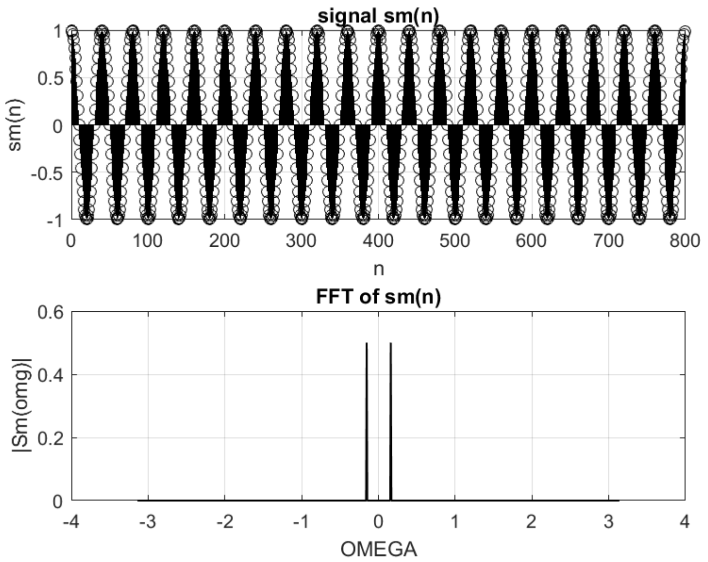


Figure 9 – The LF cosine signal in the time and frequency domain
Рис. 9 – Низкочастотный косинусоидальный сигнал во временной и частотной областях
Слика 9 – НФ косинусни сигнал у временском и фреквенцијском домену

A simulated LF cosine pulse in the time and frequency domain is shown in Figure 10. The cosine pulse $m(n)$ has the amplitudes A = 2 in the interval from n = 0 to n =80. It is not a periodic function, and its spectrum is a shifted version of the spectrum of the rectangular pulse to the frequency Ω_m. The graphs in Figure 10 correspond to the theoretical graphs shown in Figure 5.

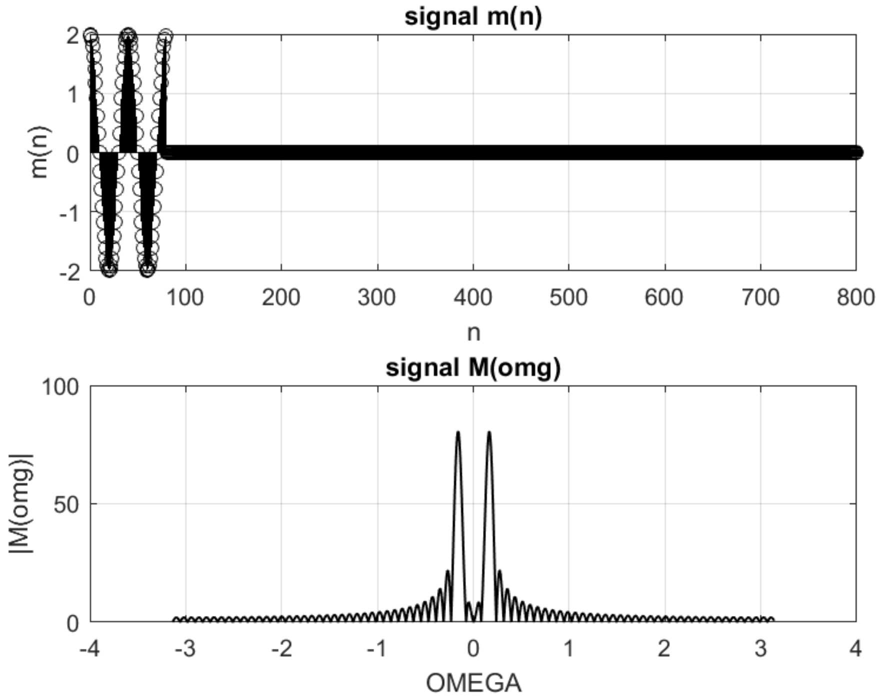


Figure 10 – LF cosine pulse in the time and frequency domain
Рис. 10 – Низкочастотный косинусоидальный сигнал во временной и частотной областях
Слика 10 – НФ косинусни пулс у временском и фреквенцијском домену

The simulated high-frequency carrier is shown in the time and frequency domain in Figure 11. The processed carrier was in the interval from n = 0 to n = 800. In Figure 11, only a part of the signal is shown for the sake of understanding its shape. These graphs correspond to the theoretically expected graphs presented in Figure 6.

The simulated modulated signal in the time and frequency domain is presented in Figure 12. The same signal in the time domain is presented in an extended form in Figure 13. These graphs correspond to the theoretically expected graphs presented in Figure 7.

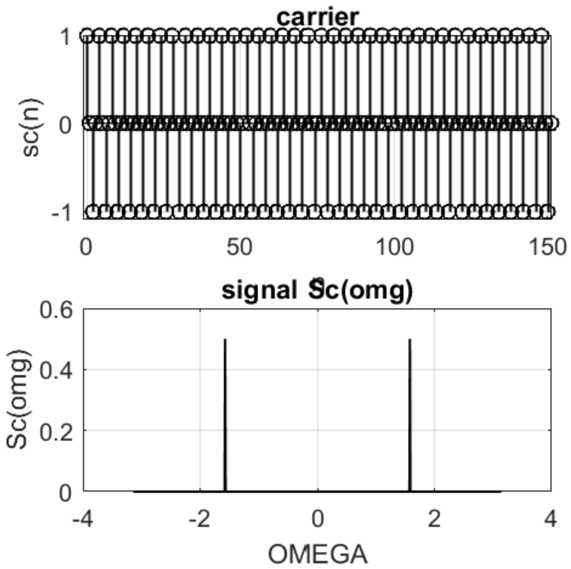


Figure 11 – The carrier signal in the time and frequency domain
Рис. 11 – Несущая волна во временной и частотной областях
Слика 11 – Носилац у временском и фреквенцијском домену

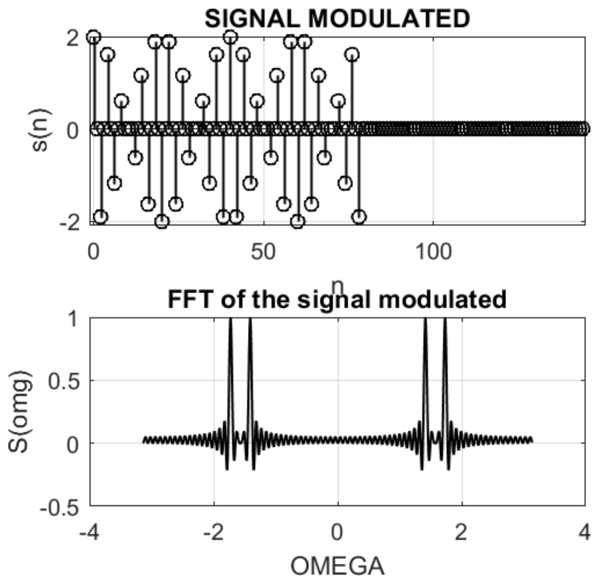


Figure 12 – Modulated signal in the time and frequency domain
Рис. 12 – Модулированный сигнал во временной и частотной областях
Слика 12 – Модулисани сигнал у временском и фреквенцијском домену

To see the shape of the signal, the modulated signal *s*(*n*) is presented in the whole interval from *n* = 0 to *n* = *N*-1 in Figure 13.

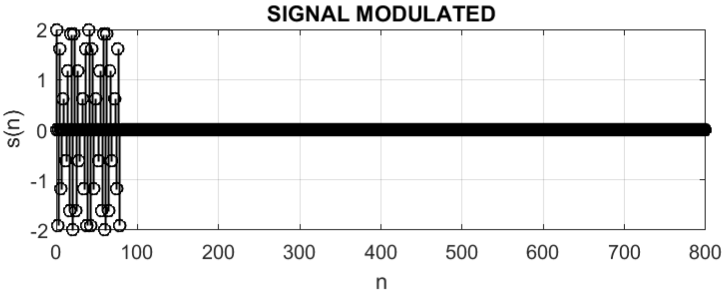


Figure 13 – Modulated signal in the time domain
Рис. 13 – Модулированный сигнал во временной области
Слика 13 – Модулисани сигнал у временском домену

Pulse demodulator

The demodulation of the discrete modulated signal *s*(*n*) results in the discovery of the modulating cosine and the rectangular pulse. The receiver blocks involved in the procedure of received signal demodulation are presented in Figure 1.

The output signal of the demodulator multiplier. Firstly, the received discrete modulated signal is multiplied by the carrier to get the signal

$$s_{cm}(n) = s(n)\cos\Omega_c n = \begin{Bmatrix} m(n)\cos^2\Omega_c n & 0 \le n \le N-1 \\ 0 & otherwise \end{Bmatrix}$$
$$= \begin{Bmatrix} \dfrac{1}{2}m(n)(1+\cos 2\Omega_c n) & 0 \le n \le N-1 \\ 0 & otherwise \end{Bmatrix} . \quad (28)$$

The signal can be expressed in this form in the time domain

$$s_{cm}(n) = \begin{Bmatrix} \dfrac{1}{2}A\cos\Omega_m n + \dfrac{1}{2}\dfrac{1}{2}A\cos(2\Omega_c + \Omega_m)n + \dfrac{1}{2}\dfrac{1}{2}A\cos(2\Omega_c - \Omega_m)n & 0 \le n \le N-1 \\ 0 & otherwise \end{Bmatrix} \quad (29)$$

Therefore, the DTFT of this signal gives us its amplitude spectral density expressed as

$$S_{cm}(\Omega) = \frac{1}{2}FT\{m(n)(1+\cos 2\Omega_c n)\} = \frac{1}{2}FT\{m(n)+m(n)\cos 2\Omega_c n\}$$
$$= \frac{1}{2}M(\Omega) + \frac{1}{4}[M(\Omega - 2\Omega_c) + M(\Omega + 2\Omega_c)] , \quad (30)$$

where the first component $M(\Omega)$ is the LF component containing the spectrum of the modulating cosine pulse and its shifted spectrum to the doubled carrier frequency. The LF component can be expressed as

$$\frac{1}{2}M(\Omega)=\frac{1}{2}FT\{p(n)\cos\Omega_m n\}=\frac{1}{4}[P(\Omega-\Omega_m)+P(\Omega+\Omega_m)], \quad (31)$$

where the shifted components are

$$P(\Omega-\Omega_m)=\left.\begin{cases} AN & \Omega-\Omega_m=\pm 2k\pi, k=0,1,2,3,\ldots \\ Ae^{-j(\Omega-\Omega_m)(N-1)/2}\dfrac{\sin((\Omega-\Omega_m)N/2)}{\sin((\Omega-\Omega_m)/2)} & \text{otherwise} \end{cases}\right|_{N=80}$$

$$P(\Omega+\Omega_m)=\left.\begin{cases} AN & \Omega+\Omega_m=\pm 2k\pi, k=0,1,2,3,\ldots \\ Ae^{-j(\Omega+\Omega_m)(N-1)/2}\dfrac{\sin((\Omega+\Omega_m)N/2)}{\sin((\Omega+\Omega_m)/2)} & \text{otherwise} \end{cases}\right|_{N=80}$$

To obtain the multiplied signal $S_{cm}(\Omega)$ expressed by (30), we can calculate the shifted spectral components as follows

$$\frac{1}{4}M(\Omega-2\Omega_c)=\frac{1}{4}\frac{1}{2}[P(\Omega-2\Omega_c+\Omega_m)+P(\Omega-2\Omega_c-\Omega_m)], \quad (32)$$

and

$$\frac{1}{4}M(\Omega+2\Omega_c)=\frac{1}{4}\frac{1}{2}[P(\Omega+2\Omega_c+\Omega_m)+P(\Omega+2\Omega_c-\Omega_m)]. \quad (33)$$

Finally, the spectrum of the signal (30) is expressed as

$$S_{cm}(\Omega)=\frac{1}{4}[P(\Omega-\Omega_m)+P(\Omega+\Omega_m)]+\frac{1}{8}[P(\Omega-2\Omega_c+\Omega_m)+P(\Omega-2\Omega_c-\Omega_m)] \\ +\frac{1}{8}[P(\Omega+2\Omega_c+\Omega_m)+P(\Omega+2\Omega_c-\Omega_m)], \quad (34)$$

and is presented in Figure 14. The power and energy of the signal in the time domain can be calculated from (29) and expressed as

$$E_{cm}=P_{cm}\cdot N=\sum_{n=0}^{N-1}s_{cm}^2(n)$$
$$=\sum_{n=0}^{N-1}(\frac{1}{2}A\cos\Omega_m n)^2+\sum_{n=0}^{N-1}(\frac{1}{4}A\cos(2\Omega_c+\Omega_m)n)^2+\sum_{n=0}^{N-1}(\frac{1}{4}A\cos(2\Omega_c-\Omega_m)n)^2 \quad (35)$$
$$=\frac{1}{4}\sum_{n=0}^{N-1}\frac{1}{2}A^2+\frac{1}{16}\sum_{n=0}^{N-1}\frac{1}{2}A^2+\frac{1}{16}\sum_{n=0}^{N-1}\frac{1}{2}A^2=\frac{1}{8}A^2N+\frac{1}{32}A^2N+\frac{1}{32}A^2N=\frac{3}{16}A^2N$$

and the power is $P_{cm}=E_{cm}/N=3A^2/16$. The energy can be calculated in the frequency domain as

$$E_{cm} = \frac{1}{2\pi}\int_{-\pi}^{\pi} |S_{cm}(\Omega)|^2 \, d\Omega$$

$$= \frac{1}{2\pi}\int_{-\pi}^{\pi} \begin{matrix} |\frac{1}{4}[P(\Omega-\Omega_m)+P(\Omega+\Omega_m)]+\frac{1}{8}[P(\Omega-2\Omega_c+\Omega_m)+P(\Omega-2\Omega_c-\Omega_m)] \\ +\frac{1}{8}[P(\Omega+2\Omega_c+\Omega_m)+P(\Omega+2\Omega_c-\Omega_m)]|^2 \, d\Omega \end{matrix} \quad (36)$$

$$= 2\frac{A^2}{2\pi}\frac{1}{16}2N\pi + 4\frac{A^2}{2\pi}\frac{1}{64}2N\pi = \frac{3}{16}A^2N$$

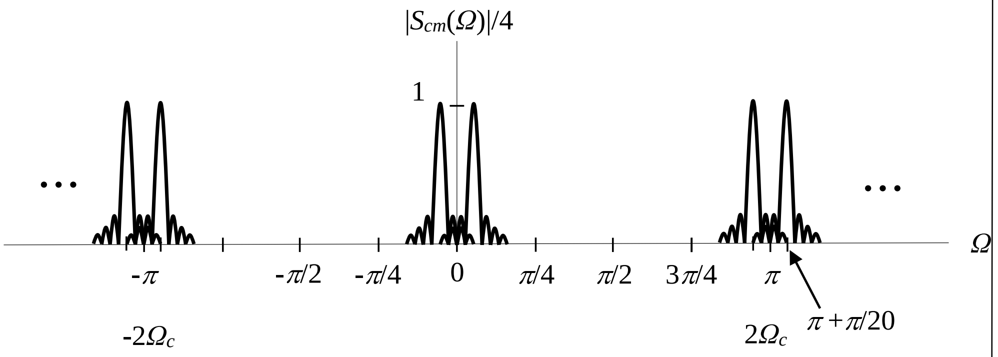


Figure 14 – Magnitude spectral density of the signal at the output of the receiver multiplier
Рис. 14 – Величина спектральной плотности сигнала на выходе приемного умножителя
Слика 14 – Спектрална густина магнитуде сигнала на излазу множача пријемника

Extraction of the baseband rectangular pulse. This extraction starts with a multiplication of the demodulated signal by an LF cosine term as follows

$$s_{mm}(n) = s_{cm}(n)\cos\Omega_m n \,. \quad (37)$$

Using the modulation theorem, the amplitude spectral density of this signal will be expressed as a shifted version of the spectrum in (34), which gives

$$
\begin{aligned}
S_{mm}(\Omega) &= \frac{1}{4}P(\Omega) + \frac{1}{8}[P(\Omega - 2\Omega_m) + P(\Omega + 2\Omega_m)] \\
&+ \frac{1}{4}[P(\Omega - 2\Omega_c) + P(\Omega + 2\Omega_c))] \\
&+ \frac{1}{8}[P(\Omega - 2\Omega_c - 2\Omega_m) + P(\Omega - 2\Omega_c + 2\Omega_m)] \\
&+ \frac{1}{8}[P(\Omega + 2\Omega_c + 2\Omega_m) + P(\Omega + 2\Omega_c - 2\Omega_m)]
\end{aligned}
, \qquad (38)
$$

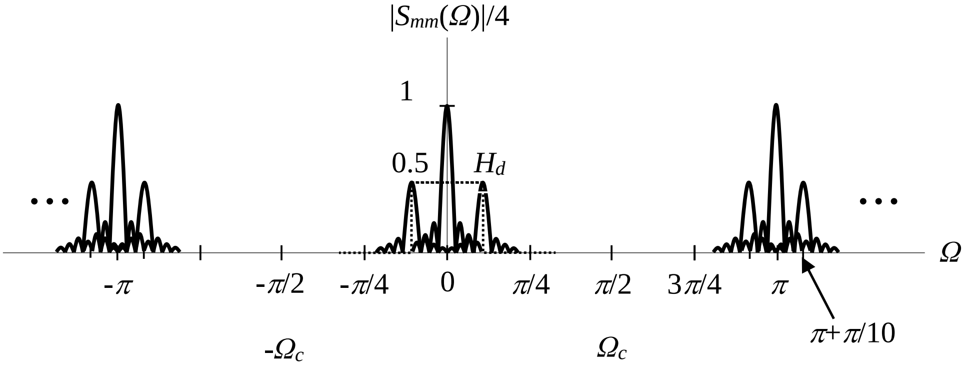


Figure 15 – Magnitude spectral density of $s_{mm}(n)$
Рис. 15 – Спектральная плотность амплитуды сигнала $s_{mm}(n)$
Слика 15 – Спектрална густина магнитуде сигнала $s_{mm}(n)$

The calculated spectrum contains an LF part around the zero frequency, which contains the spectrum of the modulating rectangular pulse. We can use an LP filter to extract this signal. This operation will be approximate, meaning that a part of the spectrum of the neighboring components to the pulse spectrum will be added to the signal causing distortion. Also, the pulse spectrum will be reduced to its two arcades which will reduce the power of the signal. We will take this reduction of the power in the following considerations and calculations.

LPF operation in the time and frequency domain. An ideal LP filter with the gain H_d is used to eliminate the HF components in this spectrum and obtain the demodulated signal representing the rectangular pulse $p(n)$ that was sent by the transmitter. The filter eliminated all high-frequency components and the result is the LF pulse

$$S_{md}(\Omega) = H_d(\Omega) \cdot S_{mm}(\Omega) = H_d(\Omega) \cdot \frac{1}{4} P(\Omega), \tag{39}$$

where the filter transfer characteristic is rectangular as shown in Figure 15 by a dotted graph of the amplitude H_d. If there is no attenuation of the filter, i.e., $H_d = 1$, an approximation of the output spectrum can be obtained as shown in Figure 16. Due to the limitation of the spectrum of the demodulated pulse $p(n)$ at the receiver side, the received pulse at the output of the LP filter will not be rectangular as the simulation will confirm. In the time domain, the output signal of the filter, $m_d(n)$, will be a convolution of the filter input signal $s_{mm}(n)$ and the impulse response of the filter $h_d(n)$, as will be shown in the simulation. The result of this convolution is the pulse $m_d(n)$, which is a distorted version of the rectangular pulse.

Calculation of the system attenuation. The total value of the demodulated rectangular pulse energy can be calculated from the pulse spectrum in Figure 15, assuming an all-pass LF filter and ideal filtering, as

$$\begin{aligned} E_{md} &= \frac{1}{2\pi}\int_{-\pi}^{\pi} |S_{md}(\Omega)|^2 \, d\Omega = \frac{1}{2\pi}\int_{-\pi}^{\pi} |H_d(\Omega) \cdot \frac{1}{4} P(\Omega)|^2 \, d\Omega \\ &\underset{H_d=1}{=} \frac{1}{32\pi}\int_{-\pi}^{\pi} |P(\Omega)|^2 \, d\Omega = \frac{A^2}{32\pi} 2N\pi = \frac{1}{18} A^2 N \end{aligned} . \tag{40}$$

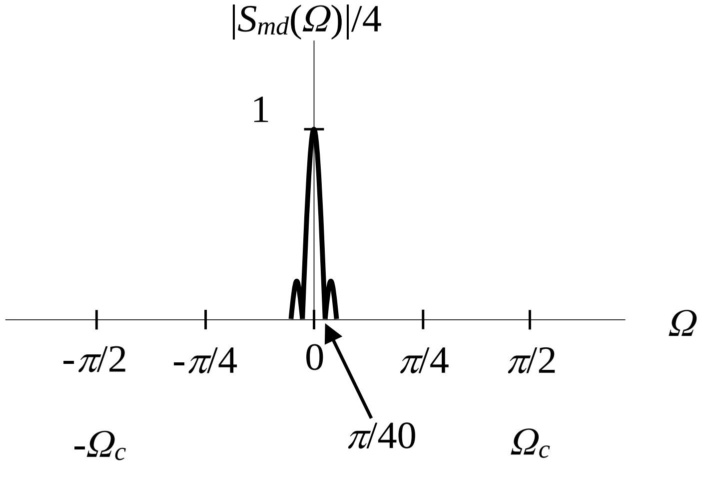


Figure 16 – Magnitude spectral density of the demodulated pulse $m_d(n)$
Рис. 16 – Величина спектральной плотности демодулированного импульса $m_d(n)$
Слика 16 – Спектрална густина магнитуде демодулисаног пулса $m_d(n)$

If we use an LP filter with the cut-off frequency of π/20, the precise value of the energy of the received pulse is

$$E_{p-Filter}=\frac{1}{32\pi}\int_{-\pi}^{\pi}\left|P\left(\Omega\right)\right|^{2}d\Omega=\frac{A^{2}}{32\pi}\int_{-\pi/20}^{\pi/20}\left|\frac{\sin 40\Omega}{\sin(\Omega/2)}\right|^{2}d\Omega \quad . \qquad (41)$$
$$=\frac{A^{2}}{32\pi}477.5439727897149=4.75A^{2}=0.0594NA^{2}$$

This energy of the signal is much smaller than the energy of the pulse at the transmitter side, which was NA^2, as calculated in (6). The energy of this pulse in its two arcades is

$$E_{p}=\frac{1}{2\pi}\int_{-\pi}^{\pi}\left|P\left(\Omega\right)\right|^{2}d\Omega=\frac{A^{2}}{2\pi}\int_{-\pi/20}^{\pi/20}\left\|\frac{\sin 40\Omega}{\sin(\Omega/2)}\right\|^{2}d\Omega=\frac{A^{2}}{2\pi}2N\pi \quad . \qquad (42)$$
$$=\frac{A^{2}}{2\pi}477.5439727897149=76A^{2}=0.95NA^{2}$$

The power attenuation of the received signal is

$$a_{p}=10\log_{10}\frac{P_{p}}{P_{p-filter}}=10\log_{10}\frac{E_{p}/N}{E_{p-filter}/N}=10\log_{10}\frac{0.95A^{2}}{0.0594A^{2}}=12.04\text{ dB.} \qquad (43)$$

To receive the pulse with the required power, we need to use amplifiers in the receiver. These amplifiers will compensate for the loss of power caused by the explained signal processing. However, due to the propagation of the signal, there will exist additional attenuation that needs to be compensated by the amplification inside the receiver. Finally, as shown in Figure 1, there will be a noise present in the channel that is added to the signal. The noise influence on the signal transmission needs to be also considered, which is a separate problem in the analysis of the system.

If we are interested in the detection of the phase of the transmitted cosine pulse, we can use a correlator on the receiver side. In that case, the polarity of the correlator output will give us evidence about the phase of the transmitted pulse.

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2023, Vol. 71, Issue 3

Simulation of the receiver

The receiver operation is simulated in Matlab. The simulated operation of the first modulation multiplier is presented by the graphs of its output discrete-time signal $s_{cm}(n)$ in the time and frequency domain in Figure 17, which was theoretically analyzed and presented in the frequency domain in Figure 14.

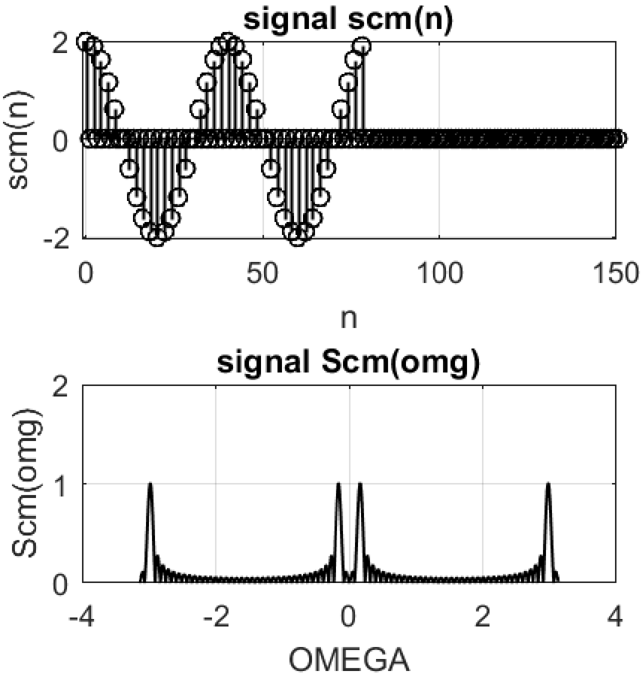


Figure 17 – Magnitude spectral density of the simulated signal at the output of the receiver multiplier
Рис. 17 – Величина спектральной плотности моделируемого сигнала на выходе умножителя приемника
Слика 17 – Спектрална густина магнитуде симулисаног сигнала на излазу множача пријемника

This signal is multiplied by an LF signal $s_m(n)$ to get the signal $s_{mm}(n)$ that contains a low-frequency component that represents the modulating signal. The simulated signal in the time and frequency domain is shown in Figure 18. The corresponding signal, theoretically calculated, is presented in Figure 15.

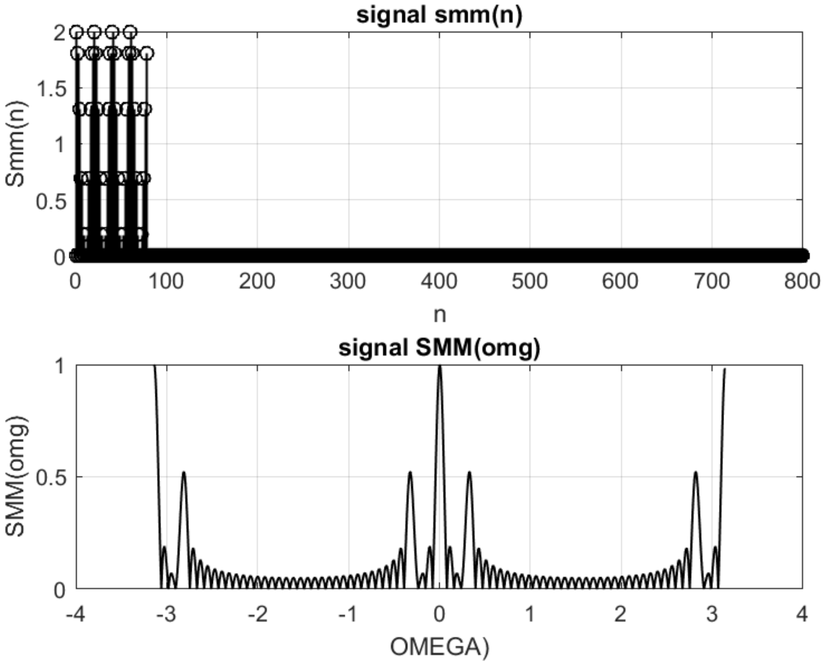


Figure 18 – Magnitude spectral density of the simulated $s_{mm}(n)$
Рис. 18 – Спектральная плотность моделируемой величины s_{mm}(n)
Слика 18 – Спектрална густина магнитуде симулисаног $s_{mm}(n)$

The LF signal $s_{mm}(n)$ is processed in the LP filter to get the LF modulating signal. For the filter transfer characteristic shown in Figure 14, the impulse response $h_d(n)$ is calculated.

Then the convolution of this impulse response and the input signal $s_{mm}(n)$ is performed in the time domain as shown in Figure 19.

The LPF is a linear time-invariant discrete-time system, and this convolution can be performed.

The result of the convolution is the positive pulse $m_d(n)$ that is generated at the output of the receiver and corresponds to the rectangular pulse sent at the transmitter side.

This pulse obtained by simulation is presented in Figure 20.

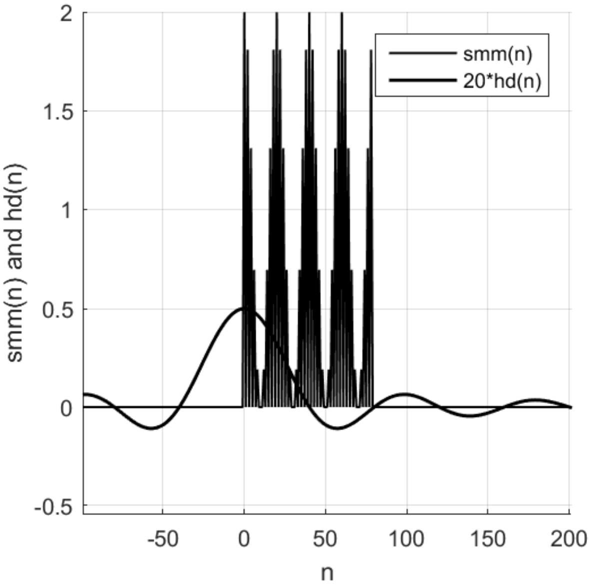


Figure 19 – Procedure of convolution to get the demodulated pulse $m_d(n)$
Рис. 19 – Процедура свертки для получения демодулированного импульса $m_d(n)$
Слика 19 – Процедура конволуције за добијање демодулисаног пулса $m_d(n)$

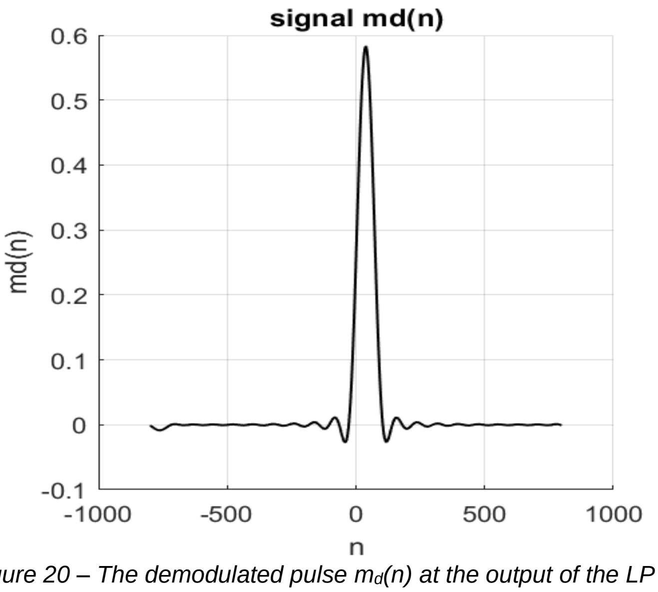


Figure 20 – The demodulated pulse $m_d(n)$ at the output of the LP filter
Рис. 20 – Демодулированный импульс $m_d(n)$ на выходе фильтра нижних частот
Слика 20 – Демодулисани пулс $m_d(n)$ на излазу НФ филтера

Conclusions

This paper presented the theoretical model and the simulation results of a communication system analysis for a cosine pulse transmission. A detailed block schematic of the system's transmitter and receiver is presented in the form of mathematical operators and all input-output signals are presented in both time and frequency domains using exact mathematical expressions. To calculate the attenuation of the signals in the system, the powers and the energies of the signals are calculated for all signals processed in the system.

It is shown that the application of a low-pass filter inside the receiver allows the detection of the modulating signal, despite its distortion due to the processing in the system. The signals in the analyzed blocks of the transceiver are processed in the discrete-time domain. All theoretical results are confirmed by simulations.

References

Abramowitz, M. & Stegun, I.A. 1972. *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables.* Washington, D.C.: United States Department Of Commerce, National Bureau of Standards, Applied Mathematics Series – 55 [online]. Available at: https://personal.math.ubc.ca/~cbm/aands/frameindex.htm [Accessed: 20 March 2023].

Benvenuto, N., Corvaja, R., Erseghe, T. & Laurenti, N. 2007. *Communication Systems, Fundamentals and Design Methods*. Hoboken, NJ, USA: John Wiley & Sons, Inc. ISBN-13: 978-0470018224.

Berber, S. 2009. *Deterministic and Stochastic Signal Processing: Continuous and Discrete-time Signals.* VDM Verlag Dr. Müller. ISBN-13: 978-3639111880.

Berber, S. 2019. Discrete time domain analysis of chaos-based wireless communication systems with imperfect sequence synchronization. *Signal Processing*, 154, pp.198-206. Available at: https://doi.org/10.1016/j.sigpro.2018.09.010.

Berber, S. 2021. *Discrete Communication Systems*. Oxford, UK: Oxford University Press. ISBN-13: 978-0198860792.

Cavicchi, T.J. 2000. *Digital Signal Processing, Solutions Manual.* Hoboken, NJ, USA: John Wiley & Sons, Inc. [Accessed: 20 March 2023].

Haykin, S. 2014. *Digital Communication Systems, 1st edition.* Hoboken, NJ, USA: John Wiley & Sons, Inc. ISBN-13: 978-0-471-64735-5.

Ingle, V.K. & Proakis, J.G. 2012. *Digital signal processing using MATLAB*, *3rd edition*. Stamford, CT, USA: Cengage Learning. ISBN-13: 978-1-111-42737-5.

-Integral calculator. 2023. *Calculate integrals online − with steps and graphing!* [online]. Available at: https://www.integral-calculator.com [Accessed: 20 March 2023].

Manolakis, D.G., Ingle, V.K. & Kogan, S.M. 2005. *Statistical and Adaptive Signal Processing: Spectral Estimation, Signal Modeling, Adaptive Filtering and Array Processing, Illustrated edition*. Norwood, MA, USA: Artech House. ISBN-13: 978-1580536103.

Miao, G.J. 2007. *Signal Processing in Digital Communications*. Norwood, MA, USA: Artech House. ISBN 13: 978-1-58053-667-7.

Nguyen, X.Q, Vu, V.Y. & Trung, Q.D. 2015. Design and analysis of a spread-spectrum communication system with chaos-based variation of both phase-coded carrier and spreading factor. *IET Commun*., 9(12), pp.1466-1473. Available at: https://doi.org/10.1049/iet-com.2014.0907.

Papoulis, A. & Pillai, S.U. 2002. *Probability, Random Variables, and Stochastic Processes, 4th edition.* McGraw-Hill Europe. ISBN-13: 978-0071226615.

Proakis, J.G. 2001. *Digital Communications, 4th edition.* McGraw Hill Higher Education. ISBN-13: 978-0071181839.

Rice, M. 2009. *Digital Communications: A Discrete-time Approach*, *1st edition*. London, UK: Pearson Prentice Hall. ISBN-13: 978-0130304971.

Разработка приемопередатчика косинусоидальных импульсов в дискретном времени

Стеван М. Бербер

Университет Окленда,
Кафедра электротехники, вычислительной техники и программного обеспечения, г. Окленд, Новая Зеландия

РУБРИКА ГРНТИ: 50.07.03 Теория и моделирование вычислительных сред, систем, комплексов и сетей
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье обсуждаются вопросы теории и разработки приемопередатчика для передачи косинусоидальных импульсов в дискретном времени. Работа приемопередатчика и все сигналы анализируются как во временной, так и в частотной областях.

Методы: В данной статье приведен подробный обзор теоретических моделей приемопередатчика на основе его блок-схем, которые представлены с помощью математических операторов. Результаты смоделированных блоков приемопередатчика были сопоставлены с результатами теоретического анализа.

Результаты: Сигналы дискретного времени на входах и выходах каждого блока приемопередатчика выводятся в математической форме и отображаются во временной и частотной областях. Симулятор приемопередатчика был разработан в Matlab. Теоретические выводы подтверждены результатами моделирования.

Выводы: Результаты данной статьи способствуют теоретическому моделированию и разработке современных примоередатчиков, которые можно будет использовать для передачи дискретного косинусоидального импульса.

Ключевые слова: разработка приемопередатчика, дискретный косинусоидальный импульс, импульсный приемопередатчик, математическое моделирование приемопередатчика, фильтрация, симулятор приемопередатчика.

Дизајн примопредајника косинусног пулса у дискретном времену

Стеван М. Бербер

Универзитет у Окланду,
Катедра за електротехнику, рачунарску и софтверску технику,
Окланд, Нови Зеланд

ОБЛАСТ: електротехника, телекомуникације
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Дизајн примопредајника косинусног пулса приказан је у дискретном времену. Рад примопредајника и сви сигнали анализирани су у временском и фреквенцијском домену.

Методе: Приказани су детаљни теоријски модели предајника и пријемника базирани на њиховим блок-шемама које су представљене помоћу математичких оператора. Блокови примопредајника су симулирани, а резултати симулације упоређени са резултатима теоријске анализе.

Резултати: Сигнали дискретног времена на улазима и излазима сваког блока у примопредајнику изведени су у математичком облику и приказани у временском и фреквенцијском домену. Развијен је симулатор примопредајника у Матлаб-у. Резултати симулације су потврдили теоријске налазе.

Закључак: Резултати овог рада доприносе теоријском моделовању и дизајну модерних приморедајника који се могу користити за пренос дискретног косинусног пулса.

Кључне речи: дизајн примопредајника, дискретни косинусни пулс, примопредајник пулса, математичко моделовање примопредајника, филтрирање, симулатор примопредајника.

Paper received on / Дата получения работы / Датум пријема чланка: 23.03.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 12.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 14.06.2023.

Image clutter metrics and target acquisition performance

Boban P. Bondžulić[a], *Dimitrije* M. Bujaković[b], *Jovan* G. Mihajlović[c]

[a] University of Defence in Belgrade, Military Academy, Department of Telecommunications and Informatics, Belgrade, Republic of Serbia, e-mail: bondzulici@yahoo.com, ORCID iD: https://orcid.org/0000-0002-8850-9842

[b] University of Defence in Belgrade, Military Academy, Department of Military Electronic Engineering, Belgrade, Republic of Serbia e-mail: dimitrijebujakovic@gmail.com, **corresponding author**, ORCID iD: https://orcid.org/0000-0001-7058-9293

[c] Serbian Armed Forces, General Staff, Telecommunications and Information Technology Directorate (J-6), Signal Brigade, Belgrade, Republic of Serbia, e-mail: mihajlovicjovan@yahoo.com, ORCID iD: https://orcid.org/0009-0001-7752-6196

DOI: 10.5937/vojtehg71-44117; https://doi.org/10.5937/vojtehg71-44117

FIELD: telecommunications
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Measuring target acquisition performance in imaging systems with human-in-the-loop plays an essential role in military applications. This paper presents an extended review on the application of image clutter metrics for target acquisition, with the aim of using objective measures to predict the detection probability, false alarm probability and mean search time of the target in the image.

Methods: To determine the degree of clutter, simple features on the global (picture-wise) and local (target-wise) level were used as well as contrast-based clutter metrics, target size and metrics derived from image quality assessment measures. Along with the standard ones, the features derived from the distribution of mean subtracted contrast normalized coefficients were also used. To compare the results of the objective scores and the experimental results obtained on the publicly available Search_2 dataset, regression laws accepted in the literature were applied. Linear correlations and rank correlations were used as quantitative measures of agreement.

ACKNOWLEDGMENT: The authors thank Dr. Alexander Toet for kindly providing the Search_2 dataset and the implementation of the TSSIM clutter metric.

Results: It is shown that the best agreement with target acquisition indicators is obtained by applying clutter metrics derived from image quality assessment measures. The correlation with the results of subjective tests is up to 90%, which indicates the need for further research. A special contribution of the paper is the analysis of the target acquisition prediction performance using simple features at the global and local level, where it is shown that the prediction performance can be improved by determining the features around the target. Furthermore, it was shown that the false alarm probability and the probability of detection can be predicted based on the mean target search time in the image with a probability higher than 90%.

Conclusion: In addition to obtaining a high degree of agreement between the objective metrics of clutter and the results of subjective tests (up to 90%), there is a need to improve the existing and develop new metrics as well as to conduct new subjective tests.

Key words: clutter metric, false alarm rate, mean search time, probability of detection, target acquisition.

Introduction

The process of target acquisition as a concept used for military purposes, includes all the processes required to detect a target in an image (Li et al, 2012). In addition, discrimination between different classes of targets (recognition) or discrimination within a class (identification) may be required. Measuring target acquisition performance in human-in-the-loop imaging systems plays an essential role in many applications.

Electro-optical imaging systems detect radiation from the background and from the target of interest. Background clutter, which refers to objects or features of the scene that are similar to the target, can confuse the observer and affect target acquisition performance. Clutter plays a significant role in the detection of targets in images obtained by surveillance devices, both in the invisible and in the visible part of the electromagnetic spectrum. Therefore, there is great interest in analyzing the relationship between image content and human (operator) detection performance (Chang & Zhang, 2006a; Gavrovska & Samčović, 2018; Lukin et al, 2023).

The presence of clutter in the image affects target detection and the search process (Schmieder & Weathersby, 1983; Chang & Zhang, 2006b). This can lead to a decrease in detection probability as some targets will be missed as opposed to situations where they will be found in the case of a less cluttered scene; it can lead to an increase in false alarm probability because scene clutter will be declared as the target of interest, and it can lead to an increase in detection time because the observer will spend time considering irrelevant clutter (Chang et al, 2007).

Image clutter metrics can be used to examine target acquisition performance - to predict detection probability, false alarm probability, and search time, as well as to correct imaging system performance models. Clutter metrics can be divided into global and local (Toet & Hogervorst, 2020; Mondal, 2022). Global metrics measure the clutter of the entire scene. Local measurements determine the clutter around the target. Also, clutter metrics can be without a priori knowledge about the target, while some of the metrics require additional information about the target, such as position, dimensions (width and height) or boundaries between the target and its background. Global measures use features derived from the complete scene image, such as standard deviation, entropy, probability of edge (POE) and similar (Rotman et al, 1996; Xiao et al, 2015b). These features can also be used locally. Additional information about the target allows to determine the contrast of the target with respect to the background at the local level, so different contrast-based clutter metrics have been defined (Xiao et al, 2015b). In addition to contrast, target detection probability is also influenced by its size (Wilson, 2001).

State-of-the-art reliable clutter metrics are derived from objective measures used to assess image quality. These are mathematical measures that require a priori knowledge about the target (target image), and based on the similarity (or dissimilarity) between the target image and the background, the degree of clutter is determined and the target acquisition performance is predicted.

Chang and Zhang (Chang & Zhang, 2006a) adapted the structural similarity index SSIM (Wang et al, 2004), to mathematically define a measure of clutter. A comparison of luminance, contrast and structure is made between the target and the background. The measure is called TSSIM – target structure similarity clutter metric, which quantitatively characterizes background clutter. In the paper (Toet, 2010), Toet considered predictions of search time and probability of detection based on the three components of SSIM/TSSIM. He concluded that luminance and contrast have no influence on human detection performance, while structural similarity SSIM/TSSIM component has the most influence on prediction performance, i.e., as structural similarity (correlation) is equivalent to matched filter, it was concluded that matched filtering predicts human visual performance in target detection. The BSD measure (Xu et al, 2013) also represents the application of the structural similarity approach in the clutter metric, whereby additional weighting is performed using information content weights. This is a multidimensional measure where three scales are used. The DSIM measure (Xu & Shi, 2013) is also structural similarity based, and it can also be considered an HVS-based measure, considering brain cognitive characteristics. The clutter metric proposed in (Xiao et al, 2015a), known as C_{essim}, is a double structural similarity metric. In addition to structural similarity, the similarity of the histogram of oriented gradients between the target and the background is also considered and used as a weight for the structure similarity metric. The objective clutter metric from (Zheng et al, 2016) can also be classified into structural approaches with adaptive extraction of structural features and additional selection of blocks that have a decisive influence on the subjective impression of the observer and influence the performance of target acquisition. Structural comparison is implemented in (Zhao et al, 2019) by comparing gray levels between neighboring pixels in four directions. After that, the similarity between the target image and the background is determined based on the Hamming distance.

In addition to the mentioned SSIM-based measures, other reliable clutter metrics can be found in the literature. In (Yang et al, 2011) an approach was proposed that uses sparse representation for the clutter metric, where feature vectors are used to describe the background and the target and where similarity of the block in which the target is located with the background blocks is determined. The authors (Xu & Shi, 2012) used low-level image features to define the clutter metric FD using phase congruency to determine the differences between the background and the target, while directional contrast is used to calculate the differences in contrast between images. The approach from (Chu et al, 2012) measures the similarity between the background and the target in the frequency domain, whereby differences that cannot be seen are not taken into consideration while visible differences are additionally weighted according to the sensitivity of the visual system using Mannos-Sakrison contrast sensitivity function which is used to filter the frequency representations of the target and the background images. The degree of agreement with the subjective test results is at the TSSIM performance level. Two texture metrics based on the gray level co-occurrence error ($GLCE_{con}$ and $GLCE_{erg}$) were used in (Culpepper, 2015) to predict detection probability and mean search time. These two measures are based on the contrast and energy of the gray level co-occurrence distribution error.

Although the images of the Search_2 dataset are in color, most research in the field of clutter metrics uses grayscale images. Researchers from (Yang et al, 2007) used images from the RGB color space for representation using quaternions (a generalization of complex numbers), which was additionally folowed with phase correlation and used to estimate clutter in color images. However, the authors concluded that color is not the dominant factor for target detection on the Search_2 dataset. The TSSIM grayscale clutter metric was extended in (Chang et al, 2010) to include color by combining channels of the perceptually uniform CIELAB color space using weighted averages. Although the degree of prediction of the probability of detection by applying color increased from 0.8 to 0.82, it can be said that there was no significant improvement in performance by applying color. The gradient clutter metric proposed in (Meehan & Culpepper, 2016) uses the Lab color domain in which the gradient is determined independently in three color channels.

Also, the interesting research is (Itti et al, 2001), in which the authors presented an effective target detector model where, in 75% of images from the Search_2 dataset, the target is detected faster using the model than by the observer.

After the introductory part, the publicly available Search_2 dataset and the experimental results are described in the second part of the paper. The image clutter metrics are described in the third part of the paper, while their performance on the Search_2 dataset is discussed in the fourth part of the paper. At the end of the paper, conclusions and directions for further research are given.

Experimental results

The TNO Human Factors Search_2 dataset contains 44 high-resolution color images (6144 x 4096 pixels), where each image contains one military vehicle considered as a target (Toet et al, 2001). The images have different complexity and were obtained by shooting in a rural environment. In addition to images, the dataset also contains binary images in which the segmentation of the target from the background was performed manually.

Also, the Excel file provides information on the conditions under which the tests were conducted, as well as the results of subjective psychophysical tests.

Search targets

Nine military vehicles were considered as targets of interest (all-terrain vehicles, infantry fighting vehicles and tanks) - Fig. 1. In order to get as close as possible to the real conditions of observing these targets, the targets were recorded in different local environments (backgrounds), at different distances, in different lighting conditions of the scene, under different orientations (Fig. 2) and with different degrees of occlusion of the target with vegetation.

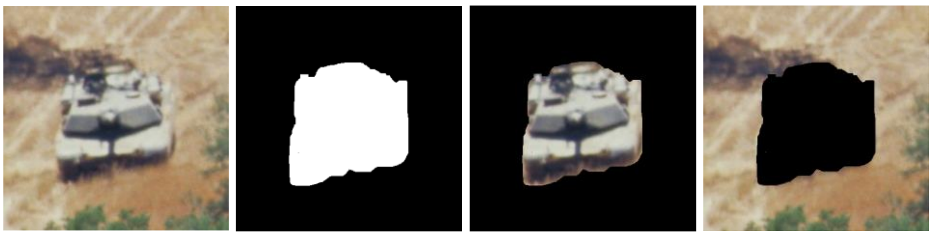
Figure 1 – Nine military vehicles considered as targets of interest (oblique back view)
Рис. 1 – Девять боевых машин, рассматриваемых в качестве целевых объектов (вид сзади)
Слика 1 – Девет војних возила разматраних као циљеви од интереса

Figure 2 – Front view, oblique front view and oblique back view of the target (tank T72)
Рис. 2 – Вид спереди, боковой вид на цель спереди и сзади на цель (танк T72)
Слика 2 – Поглед спреда, коси поглед спреда и позади на циљ (тенк T72)

Experimental results and discussion

For each of the 44 source images, the target, the distance at which the target is located and its aspect angle, the center of the target in the image, and its width and height in pixels are known. Luminance data are provided for the scene, the target and its background.

(a)



(b) (c) (d) (e)

Figure 3 – (a) source image, (b) target image, (c) binary image after manual segmentation, (d) and (e) extraction of the target and the background based on a binary image
Рис. 3 – (a) исходное изображение, (b) целевое изображение, (c) бинарное изображение после ручной сегментации, (d) и (e) извлечение цели и фона на основе бинарного изображения
Слика 3 – (a) изворна слика, (b) слика циља, (c) бинарна слика након ручне сегментације, (d) и (е) издвајање циља и околине на основу бинарне слике

These data enable the target image to be extracted, and the binary images enable the target to be extracted from the background - Fig. 3. Researchers mostly use 39 out of the available 44 images, i.e., in the analyses they do not consider images with serial numbers 7, 15, 23 and 26, in which duplicate targets have been noticed, and they do not consider image 39 because the target detection probability is only 14.5% (Chang & Zhang, 2006a).

In the subjective tests, 62 observers participated, and the results are given through their correct, false and missed detections. In addition, search time was measured, with mean, geometric mean and median search time available. Based on the results of the subjective tests, it is possible to determine the probability of detection (P_d) and the probability of false alarm (*FAR*) of the target for each source image (Chang et al, 2010):

$$P_d = \frac{N_{correct}}{N_{correct} + N_{false} + N_{missed}}, \qquad (1)$$

where $N_{correct}$ is the number of correct detections, N_{false} is the number of false detections, and N_{missed} is the number of missed targets. The false alarm probability is obtained as:

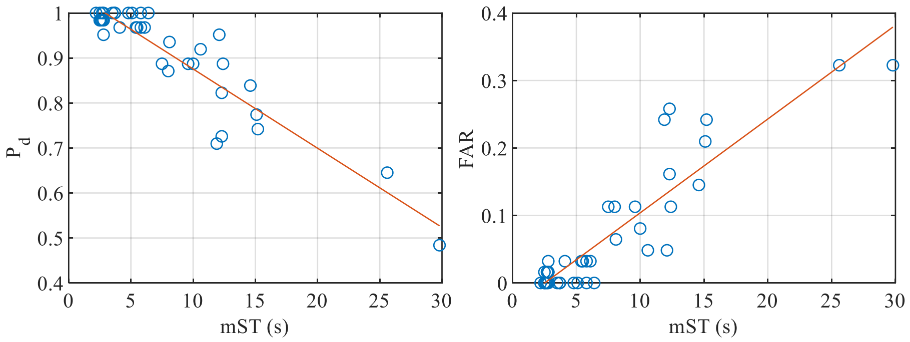
$$FAR = \frac{N_{false}}{N_{correct} + N_{false} + N_{missed}}, \qquad (2)$$

while the total probability of detection is:

$$P_{d\,\mathrm{total}} = P_d + FAR. \qquad (3)$$

Fig. 4 shows the relationship between P_d/*FAR* as a function of mean search time (*mST*) based on the Search_2 dataset data. From this figure, it can be seen that with an increase in the mean search time, the probability of detection decreases, that is, the probability of a false alarm increases. Also, Fig. 4 confirms that human observers in an attempt to improve their detection performance will accept higher false alarm probabilities when considering an image with pronounced clutter (Chang et al, 2007).

Table 1 shows the degree of agreement between the mean search time and the probability of detection/false alarm probability. The linear (Pearson's) correlation coefficient (LCC) and rank correlations (Spearman's, SROCC, and Kendal's, KROCC) were used as quantitative indicators. It can be concluded that the LCC between the mean search time and P_d/*FAR* is greater than 90%. The linear correlation between *mST* and P_d is greater than the correlation between *mST* and *FAR*. If the rank correlations are considered, the greater degree of agreement is between *mST* and *FAR*.



(a) *(b)*

Figure 4 – (a) relationship between the probability of detection, and (b) the false alarm rate and the mean search time
Рис. 4 – (а) соотношение между вероятностью обнаружения и (b) частотой ложной тревоги и средним временем поиска
Слика 4 – (а) однос између вероватноће детекције и (b) вероватноће лажног аларма и средњег времена претраживања

Table 1 – Degree of agreement between the mean search time and the probability of detection / false alarm probability
Таблица 1 – Степень совпадения среднего времени поиска с вероятностью обнаружения / вероятностью ложной тревоги
Табела 1 – Степен слагања средњег времена претраживања и вероватноће детекције / вероватноће лажног аларма

	P_d	FAR
LCC	0.9261	0.9038
SROCC	0.8101	0.8464
KROCC	0.6464	0.6968

From Fig. 4, it can be seen that there are several images where the detection probability is equal to one, and their mean search time is between 2 and 7 seconds. The minimum target detection probability of the considered images is 48.4%, where the mean search time is 29.8 s. Fig. 5 shows two source images with the maximum probability of detection and the source image with the lowest detection probability.

The targets in these images are framed by white rectangles and additionally shown as magnified images.

(a) P_d=1, mST=2.8 s, target size 322 x 199 pixels

(b) P_d=1, mST=6.4 s, target size 44 x 43 pixels

(c) P_d=0.484, FAR=0.323, mST=29.8 s, target size 38 x 28 pixels

Figure 5 – Examples of images from the Search_2 dataset with the maximum and minimum probability of target detection
Рис. 5 – Примеры изображений из базы данных Search_2 с максимальной и минимальной вероятностью обнаружения цели
Слика 5 – Примери слика из Search_2 базе са максималном и минималном вероватноћом детекције циља

From Fig. 5(a), it can be seen that the target is in the central part of the image, with high contrast compared to the background and with a not so pronounced clutter in its background, so it is not surprising that the probability of detection is maximum. For the target in Fig. 5(b), the probability of detection is maximum, although its contrast with the background is worse than in the previous example, the target is smaller and the background clutter is more pronounced. The minimum probability of detection is obtained for a small target with low contrast to the background and with a loss of detail. The targets in Figs. 5(b) and 5(c) are HMMVV-Tow at 3 km and M1A1 at 5.4 km, respectively, which may also affect the probability of detection. There is a frontal view on both targets.

Image clutter metrics

Simple clutter metrics

Gray level standard deviation (STD) and gray level entropy (E_1) are often used as image clutter metrics. Statistics derived from gray level co-occurrence matrices (GLCM) are also used. The following GLCM-based metrics were used in this research: contrast, correlation, energy, homogeneity, and two-dimensional entropy (E_2) (Cheng & Li, 2021). In this paper, the frequency of occurrence of pairs of gray levels at positions (m,n) and (m+1,n+1) for GLCM is analyzed, and the features derived from GLCM contain information about the structure in the image.

Spatial information (SI) and spatial frequency (SF) are used to describe the variety of source content in image and video datasets intended for quality assessment. Additionally, these features are used to analyze the complexity of images for compression purposes and to predict just noticeable differences (Bondžulić et al, 2022). In this paper, these features are considered as clutter metrics. For the grayscale image F, the SI is obtained after filtering the image using Sobel spatial masks that are sensitive to intensity changes along rows and columns:

$$SI_{std} = std_{space}\left[Sobel\left(F\right)\right], \tag{4}$$

where $Sobel(F)$ is the gradient magnitude at the local level, and where std_{space} is the notation representing the standard deviation of the values in the spatial (grayscale) image plane. In addition to the standard deviation, the root-mean-square and the mean value are used in the spatial domain (Yu & Winkler, 2013):

$$SI_{rms} = rms_{space}\left[Sobel\left(F\right)\right] \tag{5}$$

$$SI_{mean} = mean_{space}\left[Sobel\left(F\right)\right], \tag{6}$$

where the mean value proved to be the best predictor of image complexity in compression (Yu & Winkler, 2013).

The gradient magnitude can also be calculated based on the difference in gray levels of adjacent pixels by rows (RD) and columns (CD) using the following equations:

$$RD(m,n) = F(m,n) - F(m+1,n) \tag{7}$$

$$CD(m,n) = F(m,n) - F(m,n+1) \tag{8}$$

$$SF(m,n) = \sqrt{\left(RD(m,n)\right)^2 + \left(CD(m,n)\right)^2}\ . \tag{9}$$

The usual term for the gradient magnitude calculated in this way is spatial frequency (SF) (Tan et al, 2017). Based on locally calculated SF values, three characteristics can be calculated:

$$SF_{mean} = mean_{space}\left[SF\right], \tag{10}$$

$$SF_{rms} = rms_{space}\left[SF\right], \text{ and} \tag{11}$$

$$SF_{std} = std_{space}\left[SF\right]. \tag{12}$$

The probability of edge (POE) is the percentage of edge pixels relative to the number of pixels in a complete image (Chang & Zhang, 2006a). The well-known image binarization method proposed by Canny (Canny, 1986) was used to determine edge pixels.

The compression ratio (CR) is used as a measure of image complexity for compression purposes, and here it is used as a clutter metric. It is obtained as the ratio of the size of the original uncompressed image and JPEG compressed image with a quality factor of QF=100 (Corchs et al, 2016).

The only feature that uses color information in our research is colourfulness (CF). It is a well-known feature for estimating the variety and intensity of colors in an image (Hasler & Suesstrunk, 2003). CF is obtained in opponent color space derived from three RGB color planes:

$$rg = R - G \tag{13}$$

$$yb = \frac{1}{2}\left(R + G\right) - B, \tag{14}$$

where CF is defined as:

$$CF = \sqrt{\sigma_{rg}^2 + \sigma_{yb}^2} + 0.3\sqrt{\mu_{rg}^2 + \mu_{yb}^2}\ , \tag{15}$$

and σ_{rg} and σ_{yb} are standard deviations, while μ_{rg} and μ_{yb} are the mean values in *rg* and *yb* planes, respectively.

The last three image features are derived from the mean subtracted contrast normalized (MSCN) distribution (Mittal et al, 2012). The distribution of the MSCN coefficients can be modeled using the asymmetric generalized Gaussian distribution (AGGD), described by three parameters – the shape parameter ν, which controls the shape of the distribution, and the scaling parameters σ_l and σ_r, which control the spread on each side of the mode. These three parameters (ν, σ_l and σ_r) were used to determine the type of image degradation and perceptual quality, and here they are used as clutter metrics.

The mentioned features were used as clutter metrics at the global (picture) level, without a priori knowledge of the target. Additionally, these features were used as clutter metrics at the local level, where the size of the region within which these features are calculated is important. Most researchers (Chang & Zhang, 2006a; Xu & Shi, 2013), use a region that is twice the apparent size of the target in each dimension. Also, some researchers, such as (Wilson, 2001), use the width and height of the target multiplied by the square root of two to determine the dimensions of the region. In this way, for a rectangular object, an equal number of pixels are used to determine the target and background features. In this paper, an image patch that is twice the height and width of the target is used to determine the region of interest.

Contrast-based clutter metrics and a target size

The second set of metrics discussed in this paper are contrast-based clutter metrics and a target size. These metrics require complete information about the target (knowing the boundary between the target and its background).

The contrast metric measures the intensity difference between the target and its background (Schmieder & Weathersby, 1983), (Wilson, 2001). The simplest contrast measure is the difference between the mean gray level values of the target, μ_T, and its background, μ_B:

$$\Delta\mu = \left|\mu_T - \mu_B\right| . \tag{16}$$

However, this metric does not consider the internal structure of the target and the background, so in practice other contrast measures are used that consider the gray level standard deviations of the target, σ_T, and/or the background, σ_B, such as:

1) root sum of squares (RSS):

$$RSS = \sqrt{\left(\mu_T - \mu_B\right)^2 + \sigma_T^2} , \tag{17}$$

2) Doyle local contrast:

$$Doyle = \sqrt{(\mu_T - \mu_B)^2 + k(\sigma_T - \sigma_B)^2}, \; k = 1, \tag{18}$$

3) target local background contrast (TBC):

$$TBC = \frac{|\mu_T - \mu_B|}{\sigma_B}, \text{ and} \tag{19}$$

4) target interference ratio (TIR):

$$TIR = \frac{|\mu_T - \mu_B|}{\sqrt{\sigma_T^2 + \sigma_B^2}}. \tag{20}$$

To determine the background gray level mean value and the standard deviation, the size of the region within which these two features are calculated is important. In this paper, the region of interest is twice the height and width of the target.

The target size used in this analysis is the square root of the pixels on target (RPOT).

Quality assessment measures as clutter metrics

The application of objective image quality assessment measures as clutter metrics began after the work (Chang & Zhang, 2006a) in which the target structural similarity, TSSIM, clutter metric was proposed. After extracting the target image - the region outlined in red in Fig. 6, a comparison is made with the non-overlapping regions of the considered image - the regions outlined in white in Fig. 6.

Similarity is determined for each region, and the final clutter estimate is obtained as the arithmetic mean (am in the subscripts of objective measures) or as the root mean square of the obtained values (rms in the subscripts of objective measures).

This approach to determining the degree of clutter is used in the majority of objective measures. In the TSSIM objective measure, higher values correspond to a greater similarity between the target and the background, which indicates a higher degree of clutter in the image, and which will lead to a decrease in the probability of detection.

It can be said that TSSIM metric is inversely proportional to target detection probability. Contrary to this metric, some of the objective measures are directly proportional to the probability of detection, i.e., lower values of the objective scores correspond to lower values of the probability of detection.

Figure 6 – Illustration of the principle of applying clutter metrics based on image quality assessment
Рис. 6 – Иллюстрация принципов применения мер оценки шума на основе оценки качества изображения
Слика 6 – Илустрација принципа примене мера процене клатера заснованих на процени квалитета слике

The following objective measures were used in the analysis: TSSIM (Chang & Zhang, 2006a), structural (s) component of TSSIM metric (Toet, 2010), FD (Xu & Shi, 2012), BSD (Xu et al, 2013), DSIM (Xu & Shi, 2013), C_{essim} (Xiao et al, 2015a), C_{mdh} (Zhao et al, 2019), and texture-based metrics $GLCE_{con}$ and $GLCE_{erg}$ (Culpepper, 2015). The objective measures calculated as mean values and the root mean square of local similarities have the subscripts am and rms.

Target acquisition modeling and the results

The relationship between clutter metrics and P_d, *FAR* and *mST* is analyzed using the regression models (Culpepper, 2015):

$$P_{d\,\mathrm{pred}} = \frac{(C/C_{50})^E}{1+(C/C_{50})^E} \tag{21}$$

$$FAR_{\mathrm{pred}} = P_{d\,\mathrm{total}} - \frac{(C/C_{50})^E}{1+(C/C_{50})^E} \tag{22}$$

$$mST_{\text{pred}} = x \cdot C^{y} + z \,, \tag{23}$$

where $P_{d\ \text{pred}}$, FAR_{pred} and mST_{pred} are the predictions of P_d, FAR and mST based on the image clutter metric C, $P_{d\ \text{total}}$=0.988 is the total probability of detection (Chang et al, 2007), while E, C_{50}, x, y and z are the parameters of the regression models.

Tables 2-4 show the prediction performance (LCC, SROCC and KROCC) of the probability of detection, the false alarm probability and the mean search time based on simple features, determined on the global and local levels of the Search_2 dataset images. If the performance on the local level is better than that on the global level, it is shaded in gray in the tables. Additionally, the best performance according to each of the comparison criteria is marked in bold.

Table 2 – Performance of the probability of detection prediction based on simple clutter metrics

Таблица 2 – Эффективность прогнозирования вероятности обнаружения на основе простых показателей помех

Табела 2 – Перформансе предикције вероватноће детекције на основу једноставних мера процене клатера

	Global			Local		
	LCC	**SROCC**	**KROCC**	**LCC**	**SROCC**	**KROCC**
Entropy, E_1	0.2897	0.3714	0.2557	0.7025	0.7697	0.5861
Stand. Dev., STD	0.1622	0.2464	0.1580	**0.8239**	0.7624	0.5832
Contrast	0.1557	0.3850	0.2873	0.6624	0.7038	0.5286
Correlation	0.0555	0.0166	0.0217	0.7112	0.6769	0.4937
Energy	0.4391	0.4450	0.3384	0.5661	0.7006	0.5261
Homogeneity	0.3308	0.4644	0.3450	0.3986	0.4508	0.3265
Entropy, E_2	0.3353	0.4456	0.3304	0.7252	**0.7822**	**0.6062**
Spat. Freq., SF_{mean}	0.4133	0.5130	0.3936	0.5224	0.5437	0.3936
Spat. Freq., SF_{rms}	0.4260	0.5200	0.3993	0.6131	0.6299	0.4740
Spat. Freq., SF_{std}	0.4061	0.4804	0.3476	0.7222	0.7142	0.5688
Spat. Inf., SI_{mean}	0.4277	0.5479	0.4223	0.5308	0.5838	0.4309
Spat. Inf., SI_{rms}	0.4311	0.5166	0.3936	0.6373	0.6503	0.4855
Spat. Inf., SI_{std}	0.4002	0.4720	0.3419	0.7266	0.6994	0.5401
Prob. of Edge, POE	0.3973	0.4021	0.2774	0.6481	0.4182	0.2875
Comp. Ratio, CR	0.3642	0.4655	0.3522	0.4936	0.4438	0.3246
CF	0.0714	0.1392	0.0919	0.6139	0.6223	0.4740
AGGD, ν	**0.5479**	0.6357	0.4753	0.7385	0.5471	0.4050
AGGD, σ_l	0.4538	0.6405	**0.4827**	0.5433	0.5969	0.4470
AGGD, σ_r	0.4375	**0.6490**	0.4815	0.4862	0.5526	0.4071

Table 3 – Performance of the probability of false alarm prediction based on simple clutter metrics
Таблица 3 – Эффективность прогнозирования вероятности ложной тревоги на основе простых показателей помех
Табела 3 – Перформансе предикције вероватноће лажног аларма на основу једноставних мера процене клатера

	Global			Local		
	LCC	**SROCC**	**KROCC**	**LCC**	**SROCC**	**KROCC**
Entropy, E_1	0.3416	0.4259	0.2964	0.6745	0.7960	0.6235
Stand. Dev., STD	0.2166	0.3030	0.2088	**0.7909**	0.7871	0.6147
Contrast	0.1672	0.4281	0.3198	0.7135	0.7101	0.5388
Correlation	0.0032	0.0227	0.0176	0.6228	0.7029	0.5355
Energy	0.4680	0.5030	0.3920	0.5618	0.7222	0.5525
Homogeneity	0.3488	0.5000	0.3740	0.4472	0.4555	0.3275
Entropy, E_2	0.3804	0.5053	0.3782	0.7086	**0.8041**	**0.6352**
Spat. Freq., SF_{mean}	0.4346	0.5524	0.4249	0.5706	0.5426	0.3986
Spat. Freq., SF_{rms}	0.4482	0.5559	0.4249	0.6611	0.6297	0.4804
Spat. Freq., SF_{std}	0.4302	0.5120	0.3753	0.7630	0.7241	0.5738
Spat. Inf., SI_{mean}	0.4623	0.5857	0.4541	0.5693	0.5784	0.4337
Spat. Inf., SI_{rms}	0.4694	0.5533	0.4220	0.6771	0.6462	0.4891
Spat. Inf., SI_{std}	0.4427	0.5084	0.3723	0.7644	0.7052	0.5446
Prob. of Edge, POE	0.4363	0.4176	0.3010	0.6102	0.4057	0.2878
Comp. Ratio, CR	0.3773	0.5005	0.3770	0.4382	0.4570	0.3373
CF	0.0735	0.1489	0.1037	0.6244	0.6293	0.4833
AGGD, ν	**0.6087**	0.6690	0.5124	0.6583	0.5288	0.3941
AGGD, σ_l	0.5105	0.6689	0.5125	0.5297	0.5658	0.4281
AGGD, σ_r	0.4893	**0.6796**	**0.5143**	0.4530	0.5343	0.3918

From Tables 2-4, it can be concluded that at the global level (without a priori knowledge of the target) the best prediction results were obtained using the features derived from the distribution of the MSCN coefficients. If the features are applied at the local level (in the region where the target is located), the prediction performance considered through LCC is improved for all metrics, while the performance improvement through SROCC and KROCC criteria depends on the choice of metric. At the local level, the best predictors of subjective test results are the gray level standard deviation and entropy. The prediction performance using the standard deviation increased significantly when applied at the local level. It is interesting that by applying correlation and colourfulness, instead of being completely uncorrelated at the global level, good prediction results were achieved at the local level.

Table 4 – Performance of the mean search time prediction based on simple clutter metrics

Таблица 4 – Эффективность прогнозирования среднего времени поиска на основе простых показателей помех

Табела 4 – Перформансе предикције средњег времена претраживања на основу једноставних мера процене клатера

	Global			Local		
	LCC	**SROCC**	**KROCC**	**LCC**	**SROCC**	**KROCC**
Entropy, E_1	0.3354	0.4018	0.2750	0.7362	0.7086	0.5446
Stand. Dev., STD	0.1845	0.3233	0.2124	**0.8048**	0.6806	0.4901
Contrast	0.2853	0.5037	0.3976	0.6416	0.6381	0.4602
Correlation	0.0148	0.0546	0.0439	0.6922	0.6344	0.4707
Energy	0.4670	0.5164	0.4118	0.6114	0.6284	0.4779
Homogeneity	0.4106	0.4874	0.3883	0.4225	0.3739	0.2645
Entropy, E_2	0.3997	0.5013	0.3785	0.7049	**0.7337**	**0.5582**
Spat. Freq., SF_{mean}	0.4629	0.5254	0.4112	0.5489	0.4613	0.3077
Spat. Freq., SF_{rms}	0.4650	0.5242	0.3976	0.6313	0.5687	0.4003
Spat. Freq., SF_{std}	0.4226	0.4984	0.3622	0.6829	0.6713	0.4983
Spat. Inf., SI_{mean}	0.4724	0.5384	0.4248	0.5609	0.4930	0.3377
Spat. Inf., SI_{rms}	0.4689	0.5116	0.3948	0.6578	0.5941	0.4166
Spat. Inf., SI_{std}	0.4330	0.4772	0.3404	0.7301	0.6613	0.4983
Prob. of Edge, POE	0.3602	0.3477	0.2493	0.6914	0.3343	0.2275
Comp. Ratio, CR	0.3485	0.4880	0.3856	0.4542	0.4871	0.3458
CF	0.0925	0.2319	0.1743	0.6147	0.5648	0.4112
AGGD, ν	**0.5966**	**0.6369**	**0.5024**	0.6287	0.4836	0.3456
AGGD, σ_l	0.5043	0.5949	0.4493	0.5409	0.4324	0.2848
AGGD, σ_r	0.4862	0.6055	0.4619	0.4844	0.4257	0.2890

The prediction performance of the probability of detection, the false alarm probability and the mean search time using the contrast-based clutter metrics and the target size are given in Table 5. It can be concluded that the best predictors are RSS and RPOT, with RPOT being a better predictor.

The best prediction performance is for the mean search time. It is interesting to note that the performance of contrast-based clutter metrics Doyle, TBC and TIR, which use the standard deviation of the background, is significantly worse than the performance of RSS and RPOT.

Table 5 – Performance of the probability of detection, the false alarm probability and the mean search time predictions based on the contrast-based clutter metrics and the target size
Таблица 5 – Эффективность прогнозирования вероятности обнаружения, вероятности ложной тревоги и среднего времени поиска на основе контраста и размера цели
Табела 5 – Перформансе предикције вероватноће детекције, вероватноће лажног аларма и средњег времена претраживања на основу контрастних мера процене клатера и величине циља

	P_d			FAR			mST			mean
	LCC	SROCC	KROCC	LCC	SROCC	KROCC	LCC	SROCC	KROCC	
RSS	0.5573	0.5112	0.3850	0.6080	0.5636	0.4395	0.6638	0.6808	0.5147	0.5471
DOYLE	0.1301	0.1000	0.0747	0.1648	0.1447	0.1124	0.2039	0.2053	0.1525	0.1432
TBC	0.2301	0.2847	0.1896	0.1792	0.2485	0.1679	0.2431	0.1616	0.0899	0.1994
TIR	0.2897	0.3537	0.2499	0.2275	0.3232	0.2351	0.3223	0.2769	0.1797	0.2731
RPOT	0.6851	0.6608	0.5056	0.6514	0.6953	0.5505	0.7047	0.7662	0.5936	0.6459

Table 6 – Performance of the probability of detection, the false alarm probability and the mean search time predictions based on quality assessment measures
Таблица 6 – Эффективность прогнозирования вероятности обнаружения, вероятности ложной тревоги и среднего времени поиска на основе показателей оценки качества
Табела 6 – Перформансе предикције вероватноће детекције, вероватноће лажног аларма и средњег времена претраживања на основу мера процене квалитета

	P_d			FAR			mST			mean
	LCC	SROCC	KROCC	LCC	SROCC	KROCC	LCC	SROCC	KROCC	
$TSSIM_{rms}$	0.8011	0.6928	0.5372	0.7611	0.6800	0.5242	0.7936	0.7486	0.5582	0.6774
$TSSIM_{am}$	0.7718	0.7617	0.5660	0.7374	0.7870	0.6001	0.7427	0.6865	0.4901	0.6826
s_{rms}	0.6685	0.7031	0.5520	0.6498	0.7072	0.5508	0.7381	0.7901	0.5872	0.6608
s_{am}	0.6871	0.7160	0.5602	0.6593	0.7211	0.5621	0.7473	0.7946	0.5882	0.6707
FD_{rms}	0.8636	0.7170	0.5524	0.8704	0.7359	0.5688	0.8536	0.7298	0.5617	0.7170
FD_{am}	0.8552	0.7136	0.5505	0.8639	0.7323	0.5669	0.8502	0.7337	0.5654	0.7146
BSD_{rms}	0.8785	0.8050	0.6435	0.8433	0.8241	0.6644	0.8573	0.8111	0.6372	0.7738
BSD_{am}	0.8806	**0.8065**	**0.6454**	0.8495	0.8253	**0.6663**	0.8602	0.8100	0.6335	0.7753
$DSIM_{rms}$	**0.8924**	0.8000	0.6321	**0.8913**	0.8253	0.6644	**0.9006**	0.7631	0.5909	0.7733
$DSIM_{am}$	0.8914	0.7977	0.6234	0.8898	0.8245	0.6585	0.8995	0.7616	0.5827	0.7699
$GLCE_{con}$	0.8263	0.7168	0.5752	0.8304	0.7388	0.6023	0.7945	0.7357	0.5356	0.7062
$GLCE_{erg}$	0.8685	0.7855	0.6146	0.8479	0.8151	0.6555	0.8899	**0.8700**	**0.7053**	**0.7836**
C_{essim}	0.8696	0.8062	0.6292	0.8451	**0.8280**	0.6527	0.8906	0.7650	0.5936	0.7644
C_{mdh}	0.8686	0.7743	0.6119	0.8212	0.7868	0.6235	0.8599	0.8192	0.6209	0.7540

Table 6 shows the prediction performance of clutter metrics based on determining the similarity/dissimilarity between the target image and the background.

The best results according to each of the criteria are marked in gray and bold.

The degree of agreement between the objective measures and the results of subjective tests according to LCC goes up to 90.06%, according to SROCC up to 87% and according to KROCC up to 70.53%, so there is a need for further improvement of the existing and development of new clutter metrics.

This group of metrics provides better prediction results than simple metrics, contrast-based metrics and target size.

If we consider the mean value of the degree of prediction (the last column of the table), it can be concluded that the three first-ranked measures of clutter are $GLCE_{erg}$, BSD and DSIM, with a mean degree of agreement of about 78%.

Fig. 7 shows the relationships between clutter metrics ($GLCE_{erg}$ and $DSIM_{rms}$) and the experimental data of the Search_2 dataset (probability of detection, probability of false alarm and mean search time).

Non-linear regression trends can be observed between the objective scores and the experimental (subjective) data.

The scattering of points around the regression curves indicates the need for further research in the area of clutter assessment.

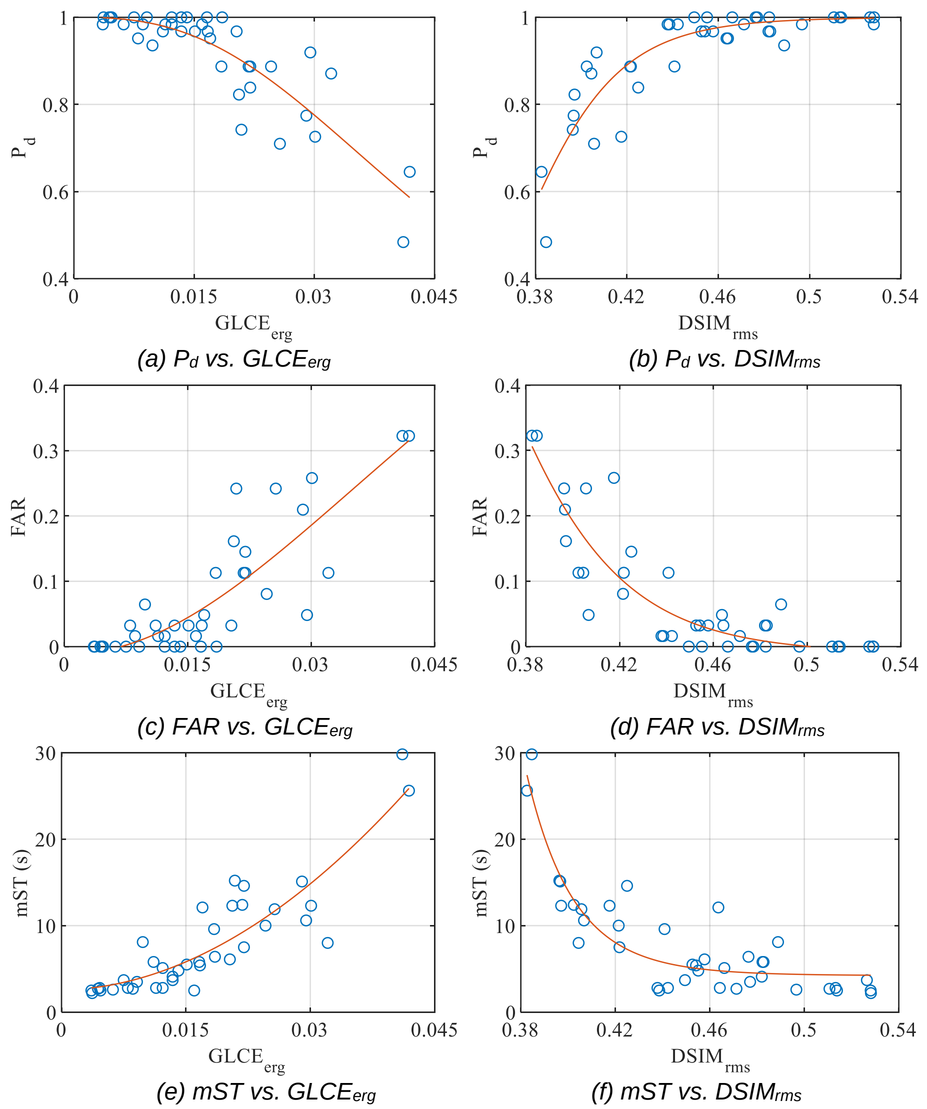


Figure 7 – Objective ($GLCE_{erg}$ and $DSIM_{rms}$) scores versus the experimental data (P_d, FAR and mST)
Рис. 7 – Соотношение ($GLCE_{erg}$ и $DSIM_{rms}$) баллов с экспериментальными данными (P_d, FAR и mST)
Слика 7 – Однос између објективних скорова ($GLCE_{erg}$ и $DSIM_{rms}$) и експерименталних података (P_d, FAR и mST)

Conclusion

The paper summarizes the results of the metrics used to determine the target acqisition performance. Global metrics without a priori knowledge of the target, metrics that require information about the position and dimensions of the target, and metrics that require full knowledge of the target information - position and boundaries between the target and the background were used. Clutter metrics were used for comparison with the results of subjective tests, that is, the relationships between the clutter metrics and the probability of target detection, the probability of a false alarm and the mean search time were analyzed. Although clutter metrics that use objective quality assessments (similarities or dissimilarities between target and background images) have achieved better results than other metrics, there is a need for further research. The degree of agreement of these metrics with the results of the subjective tests measured through the linear correlation coefficient reached a value of 90%. Since objective measures generally do not use color as information, one of the directions of future research would be related to the application of color in the analysis of the degree of clutter. Additionally, one of the directions of future research can be the simultaneous application of multiple metrics (fusion) in the image clutter analysis. The Search_2 publicly available dataset was used to analyze the performance of clutter metrics. This database is relatively small (44 images), with a relatively high target detection probability. Therefore, it is necessary to expand the range of detection probabilities in future research, and one of the ways to do that is by considering atmospheric effects.

References

Bondžulić, B., Pavlović, B., Stojanović, N. & Petrović, V. 2022. Picture-wise just noticeable difference prediction model for JPEG image quality assessment. *Vojnotehnički glasnik / Military Technical Courier*, 70(1), pp.62-86. Available at: https://doi.org/10.5937/vojtehg70-34739.

Canny, J. 1986. A computational approach to edge detection. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, PAMI-8(6), pp.679-698. Available at: https://doi.org/10.1109/TPAMI.1986.4767851.

Chang, H. & Zhang, J. 2006a. New metrics for clutter affecting human target acquisition. *IEEE Transactions on Aerospace and Electronic Systems*, 42(1), pp.361-368. Available at: https://doi.org/10.1109/TAES.2006.1603429.

Chang, H. & Zhang, J. 2006b. Evaluation of human detection performance using target structure similarity clutter metrics. *Optical Engineering*, 45(9), art.number:096404. Available at: https://doi.org/10.1117/1.2353848.

Chang, H., Zhang, J. & Liu, D. 2007. Modeling human false alarms using clutter metrics. In: *Proceedings of International Symposium on Multispectral*

Image Processing and Pattern Recognition, MIPR 2007; Automatic Target Recognition and Image Analysis; and Multispectral Image Acquisition, 67863N, Wuhan, China, 6786, pp.1-8, November 15-17. Available at: https://doi.org/10.1117/12.750260.

Chang, H., Zhang, J., Liu, X., Yang, C. & Li, Q. 2010. Color image clutter metrics for predicting human target acquisition performance. In: *2010 6th International Conference on Wireless Communications Networking and Mobile Computing (WiCOM)*, Chengdu, China, pp.1-4, September 23-25. Available at: https://doi.org/10.1109/WICOM.2010.5600622.

Cheng, X. & Li, Z. 2021. Predicting the lossless compression ratio of remote sensing images with configurational entropy. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 14, pp.11936-11953. Available at: https://doi.org/10.1109/JSTARS.2021.3123650.

Chu, X., Yang, C. & Li. Q. 2012. Contrast-sensitivity-function-based clutter metric. *Optical Engineering*, 51(6), art.number:067003. Available at: https://doi.org/10.1117/1.OE.51.6.067003.

Corchs, S.E., Ciocca, G., Bricolo, E. & Gasparini, F. 2016. Predicting complexity perception of real world images. *PLoS ONE*, 11(6), e0157986. Available at: https://doi.org/10.1371/journal.pone.0157986.

Culpepper, J.B. 2015. Texture metric that predicts target detection performance. *Optical Engineering*, 54(12), art.number:123101. Available at: https://doi.org/10.1117/1.OE.54.12.123101.

Gavrovska, A. & Samčović, A. 2018. Challenges in modeling of visual human map attention. In: *Proceedings of the 36th Symposium on Novel Technologies in Postal and Telecommunication Traffic PosTel 2018*, Belgrade, Serbia, December 4-5, pp.256-264 [online]. Available at: https://postel.sf.bg.ac.rs/simpozijumi/POSTEL2018/RADOVI%20PDF/Telekomunikacioni%20saobracaj,%20mreze%20i%20servisi/13.GavrovskaSamcovic.pdf (in Serbian) [Accessed: 20 April 2023].

Hasler, D. & Suesstrunk, S.E. 2003. Measuring colourfulness in natural images. In: *Proceedings of Electronic Imaging 2003; Human Vision and Electronic Imaging VIII,* Santa Clara, CA, USA, 5007, pp.87-95. Available at: https://doi.org/10.1117/12.477378.

Itti, L., Gold, C. & Koch, C. 2001. Visual attention and target detection in cluttered natural scenes. *Optical Engineering*, 40(9), pp.1784-1793. Available at: https://doi.org/10.1117/1.1389063.

Li, Q., Yang, C. & Zhang, J.-Q. 2012. Target acquisition performance in a cluttered environment. *Applied Optics*, 51(31), pp.7668-7673. Available at: https://doi.org/10.1364/AO.51.007668.

Lukin, V., Bataeva, E. & Abramov, S. 2023. Saliency map in image visual quality assessment and processing. *Radioelectronic and Computer Systems*, 1(105), pp.112-121. Available at: https://doi.org/10.32620/reks.2023.1.09.

Meehan, A.J. & Culpepper, J.B. 2016. Clutter estimation and perception. *Optical Engineering*, 55(11), art.number:113106. Available at: https://doi.org/10.1117/1.OE.55.11.113106.

Mittal, A., Moorty, A.K. & Bovik, A.C. 2012. No-reference image quality assessment in the spatial domain. *IEEE Transactions on Image Processing*, 21(12), pp.4695-4708. Available at: https://doi.org/10.1109/TIP.2012.2214050.

Mondal, A. 2022. Camouflage design, assessment and breaking techniques: a survey. *Multimedia Systems*, 28, pp.141-160. https://doi.org/10.1007/s00530-021-00813-6.

Rotman, S.R., Cohen-Nov, A., Shamay, D., Hsu, D. & Kowalczyk, M.L. 1996. Textural metrics for clutter affecting human target acquisition. In: *Proceedings of Aerospace/Defense Sensing and Controls; Infrared Imaging Systems: Design, Analysis, Modeling, and Testing VII,* Orlando, FL, USA, 2743, pp.99-112. Available at: https://doi.org/10.1117/12.241951.

Schmieder, D.E. & Weathersby, M.R. 1983. Detection performance in clutter with variable resolution. *IEEE Transactions on Aerospace and Electronic Systems*, AES-19(4), pp.622-630. Available at: https://doi.org/10.1109/TAES.1983.309351.

Tan, W., Zhou, H.-x., Yu, Y., Du, J., Qin, H., Ma, Z. & Zheng, R. 2017. Multi-focus image fusion using spatial frequency and discrete wavelet transform. In: *Proceedings of Applied Optics and Photonics China (AOPC2017); Optical Sensing and Imaging Technology and Applications, 104624K*, Beijing, China, 10462, pp.1-11. Available at: https://doi.org/10.1117/12.2285561.

Toet, A., Bijl, P. & Valeton, J.M. 2001. Image dataset for testing search and detection models. *Optical Engineering*, 40(9), pp.1760-1767. Available at: https://doi.org/10.1117/1.1388608.

Toet, A. 2010. Structural similarity determines search time and detection probability. *Infrared Physics & Technology*, 53(6), pp.464-468. Available at: https://doi.org/10.1016/j.infrared.2010.09.003.

Toet, A. & Hogervorst, M.A. 2020. Review of camouflage assessment techniques. In: *Proceedings of SPIE Security + Defence; Target and Background Signatures VI; 1153604,* Online Only, 11536, pp.1-29. Available at: https://doi.org/10.1117/12.2566183.

Wang, Z., Bovik, A.C., Sheikh, H.R. & Simoncelli, E.P. 2004. Image quality assessment: From error visibility to structural similarity. *IEEE Transactions on Image Processing*, 13(4), pp.600-612. Available at: https://doi.org/10.1109/TIP.2003.819861.

Wilson, D. 2001. Image-based contrast-to-clutter modeling of detection. *Optical Engineering*, 40(9), pp.1852-1857. Available at: https://doi.org/10.1117/1.1389502.

Xiao, C.-m., Shi, Z.-l. & Liu, Y.-p. 2015a. Metrics of image clutter by introducing gradient features. *Optics and Precision Engineering*, 12, pp.3472-3479 [online]. Available at: http://caod.oriprobe.com/articles/47854327/Metrics_of_image_background_clutter_by_introducing_gradient_features.htm [Accessed: 20 April 2023].

Xiao, B., Duan, J., Zhu, Y., Chen, Y. & Li, G. 2015b. Survey of evaluation methods in image complexity of target and background. In: *Proceedings of Applied Optics and Photonics China (AOPC2015); Image Processing and*

Analysis; 96751Q, Beijing, China, 9675, pp.1-6. Available at: https://doi.org/10.1117/12.2199533.

Xu, D. & Shi, Z. 2012. FD: A feature difference based image clutter metric for targeting performance. *Infrared Physics & Technology*, 55(6), pp.499-504. Available at: https://doi.org/10.1016/j.infrared.2012.08.001.

Xu, D., Shi, Z. & Luo, H. 2013. A structural difference based image clutter metric with brain cognitive model constraints. *Infrared Physics & Technology*, 57, pp.28-35. Available at: https://doi.org/10.1016/j.infrared.2012.11.005.

Xu, D. & Shi, Z. 2013. DSIM: A dissimilarity-based image clutter metric for targeting performance. *IEEE Transactions on Image Processing*, 22(10), pp.4108-4122. Available at: https://doi.org/10.1109/TIP.2013.2270112.

Yang, C., Zhang. J.-Q., Xu, X., Chang, H.-H. & He, G.-J. 2007. Quaternion phase-correlation-based clutter metric for color images. *Optical Engineering*, 46(12), art.number:127008. Available at: https://doi.org/10.1117/1.2823489.

Yang, C., Wu, J., Li, Q. & Zhang, J.-Q. 2011. Sparse-representation-based clutter metric. *Applied Optics*, 50(11), pp.1601-1605. Available at: https://doi.org/10.1364/AO.50.001601.

Yu, H. & Winkler, S. 2013. Image complexity and spatial information. In: *2013 Fifth International Workshop on Quality of Multimedia Experience (QoMEX),* Klagenfurt am Worthersee, Austria, pp.12-17, July 3-5. Available at: https://doi.org/10.1109/QoMEX.2013.6603194.

Zhao, Y., Song, Y., Sulaman, M., Li, X., Guo, Z., Yang, X. & Wang, F. 2019. A multidirectional-difference-Hash-based image clutter metric for targeting performance. *IEEE Photonics Journal*, 11(4), art.number:7801110, pp.1-10. Available at: https://doi.org/10.1109/JPHOT.2019.2922967.

Zheng, B., Wang, X.-D., Huang, J.-T., Wang, J. & Jiang, Y. 2016. Selective visual attention based clutter metric with human visual system adaptability. *Applied Optics*, 55(27), pp.7700-7706. Available at: https://doi.org/10.1364/AO.55.007700.

Показатели шума изображений и эффективность определения цели

Бобан П. Бонджулич[а], *Дмитрий* М. Буякович[а], **корреспондент**, *Йован* Г. Михайлович[б]

[а] Университет обороны в г. Белград, Военная академия, кафедра телекоммуникаций и информатики, г. Белград, Республика Сербия

[б] Вооружённые силы Республики Сербия, Генеральный штаб, Управление телекоммуникаций и информатики (J-6), Бригада связи, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 28.23.00 Искусственный интеллект,
28.23.15 Распознавание образов. Обработка изображений
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Измерение эффективности обнаружения целей в системах визуализации с непосредственным участием человека *играет важную роль в военных приложениях. В данной статье представлен расширенный обзор применения показателей шума изображений для обнаружения цели с целью использования объективных показателей для прогнозирования вероятности обнаружения, вероятности ложной тревоги и среднего времени поиска цели на изображении.*

Методы: Для определения уровня шума использовались простые функции на глобальном (с точки зрения изображения) и локальном (с точки зрения цели) уровнях, а также показатели помех на основе контраста, размера цели и показателей, полученных на основе оценки качества изображения. Наряду со стандартными, использовались признаки, полученные на основе распределения средних вычитаемых коэффициентов нормированного контраста. Для сравнения результатов объективных оценок и экспериментальных результатов, полученных в общедоступной базе данных Search_2, были применены законы регрессии, принятые в литературе. В качестве количественных показателей согласованности использовались линейные и ранговые корреляции.

Результаты: В ходе исследования доказано, что наилучшее соответствие с показателями целевого захвата достигается путем применения показателей помех, полученных на основе показателей оценки качества изображения. Корреляция с результатами субъективных тестов составляет до 90%, что указывает на необходимость дальнейших исследований. Особым вкладом статьи является анализ эффективности прогнозирования обнаружения цели с использованием простых функций на глобальном и локальном уровнях. Данный анализ показал, что эффективность прогнозирования может быть улучшена путем определения признаков в самом окружении цели. Кроме того, было показано, что вероятность ложной тревоги и вероятность обнаружения можно предусмотреть с вероятностью более 90% на основе среднего времени поиска цели на изображении.

Выводы: Помимо того, что выявлена высокая степень соответствия между объективными показателями шума изображений и результатами субъективных тестов (до 90%), выявлена и необходимость в улучшении существующих и разработке новых показателей, а также в проведении новых субъективных тестов.

Ключевые слова: показатель помехи, частота ложных тревог, среднее время поиска, вероятность обнаружения, обнаружение цели.

Мере за естимацију клатера на слици и перформансе аквизиције циља

Бобан П. Бонџулић[а], *Димитрије* М. Бујаковић[а], **аутор за преписку**, *Јован* Г. Михајловић[в]

[а] Универзитет одбране у Београду, Војна академија, Катедра телекомуникација и информатике, Београд, Република Србија

[б] Војска Србије, Генералштаб, Управа за телекомуникације и информатику (Ј-6), бригада везе, Београд, Република Србија

ОБЛАСТ: телекомуникације
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Одређивање перформанси аквизиције циља има битну улогу у војним применама у којима је човек оператер. Овај рад представља проширено истраживање о примени метрика клатера слике за анализу перформанси аквизиције циља, како би се применом објективних мера извршила предикција вероватноће детекције, вероватноће лажног аларма и средњег времена тражења циља на слици.

Методе: За одређивање степена клатера коришћена су једноставна обележја на глобалном (ниво комплетне слике) и локалном нивоу (у околини циља), метрике клатера засноване на контрасту, величина циља и објективне мере изведене из мера за процену квалитета слике. Поред стандардних обележја, коришћена су и обележја изведена из расподеле MSCN (mean subtracted contrast normalized coefficients) коефицијената. За поређење резултата објективних скорова и експерименталних резултата добијених на јавно доступној Search_2 бази, коришћени су регресиони закони прихваћени у литератури. Као квантитативне мере слагања коришћене су линеарна корелација и корелације рангова.

Резултати: Показано је да се применом метрика клатера, изведених из мера процене квалитета слике, добија најбоље слагање са показатељима аквизиције циља. Корелација са резултатима субјективних тестова износи до 90%, што указује на потребу за даљим истраживањима. Посебан допринос рада представља детаљна анализа предикције перформанси аквизиције циља применом једноставних обележја на глобалном и локалном нивоу, при чему је показано да се одређивањем обележја у околини циља могу побољшати перформансе предикције. Такође, резултати субјективних тестова показују да се са вероватноћом већом од 90% на основу средњег времена тражења циља на слици може проценити вероватноћа лажног аларма и вероватноћа детекције циља.

Закључак: Поред тога што је добијен висок степен слагања објективних метрика клатера и резултата субјективних тестова (до 90%), постоји потреба за унапређењем постојећих и развојем нових метрика, као и за спровођењем нових субјективних тестова.

Кључне речи: метрике клатера, вероватноћа лажног аларма, средње време претраживања, вероватноћа детекције, аквизиција циља.

EDITORIAL NOTE: The first author of this article, Boban P. Bondžulić, is a current member of the Editorial Board of the *Military Technical Courier*. Therefore, the Editorial Team has ensured that the double blind reviewing process was even more transparent and more rigorous. The Team made additional effort to maintain the integrity of the review and to minimize any bias by having another associate editor handle the review procedure independently of the editor – author in a completely transparent process. The Editorial Team has taken special care that the referee did not recognize the author's identity, thus avoiding the conflict of interest.

КОММЕНТАРИЙ РЕДКОЛЛЕГИИ: Первый автор данной статьи Бобан П. Бонджулич является действующим членом редколлегии журнала «Военно-технический вестник». Поэтому редколлегия провела более открытое и более строгое двойное слепое рецензирование. Редколлегия приложила дополнительные усилия для того чтобы сохранить целостность рецензирования и свести к минимуму предвзятость, вследствие чего второй редактор-сотрудник управлял процессом рецензирования независимо от редактора-автора, таким образом процесс рецензирования был абсолютно прозрачным. Редколлегия во избежание конфликта интересов позаботилась о том, чтобы рецензент не узнал кто является автором статьи.

РЕДАКЦИЈСКИ КОМЕНТАР: Први аутор овог чланка Бобан П. Бонџулић је актуелни члан Уређивачког одбора *Војнотехничког гласника*. Због тога је уредништво спровело транспарентнији и ригорознији двоструко слепи процес рецензије. Уложило је додатни напор да одржи интегритет рецензије и необјективност сведе на најмању могућу меру тако што је други уредник сарадник водио процедуру рецензије независно од уредника аутора, при чему је тај процес био апсолутно транспарентан. Уредништво је посебно водило рачуна да рецензент не препозна ко је написао рад и да не дође до конфликта интереса.

Paper received on / Дата получения работы / Датум пријема чланка: 22.04.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 10.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 12.06.2023.

Comparative analysis of the traffic accidents in the territory of the city of Užice for 2021 and 2022 using open data and the Streamlit application

Branko M. Gavrilović[a], *Jelena* Mitrović[b]

[a] Secondary School of Economics, Užice, Republic of Serbia,
e-mail: brankokumgavrilovic@gmail.com,
ORCID iD: https://orcid.org/0009-0002-1897-9192

[a] University of Passau, Faculty of Informatics and Mathematics, Passau, Federal Republic of Germany;
The Institute for Artificial Intelligence Research and Development of Serbia, Novi Sad, Republic of Serbia,
e-mail: jmitrovic@gmail.com,
ORCID iD: https://orcid.org/0000-0003-3220-8749

DOI: 10.5937/vojtehg71-44007; https://doi.org/10.5937/vojtehg71-44007

FIELD: computer sciences, IT
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: With the development of information technologies, the Internet and social networks, the amount of collected data grows year by year at high speed. Data processing and analysis is becoming a necessity without which quality business decisions cannot be made. With the development of data science, tools for processing unstructured data have also been developed. Open data is publicly available data, the processing of which allows gaining new knowledge. The goal of the work is to present the possibility of using open data for research purposes, and their processing through the Streamlit development environment.

Methods: This paper will present the Streamlit framework of the Python programming language and its functionality through the analysis of a web application for data analytics. As a case study, a comparative analysis of the traffic accident data on the territory of the Užice Police Department for 2021 and 2022 will be presented.

Results: The Streamlit application will be used for the automatic analysis of open data on the traffic accidents in the territory of the Republic of Serbia in order to process the data and test the hypothesis about whether there has been an increase in traffic safety in the territory of the Užice Police Department.

Conclusion: This work shows the possibility of using the Streamlit framework for creating an application for processing open data.

Key words: Descriptive analytics, open data, Streamlit, Pandas, Python, traffic accidents.

Introduction

This time can be rightly called the time of data. The paradigm that describes modern society was created in 2006 when the British mathematician Clive Hamby exclaimed from the roof of a building: "Data is the new oil." With the development of information technologies, the Internet and social networks, the amount of information has been growing from year to year at high speed. It is estimated that 2.7 zettabytes of data had been collected by 2013, while it is assumed that in 2025 that number will be 175 zettabytes (Daley, 2022). Data processing has become both a challenge and a necessity in order to make quality business and life decisions. The new era characterized by ubiquitous computing, big data, the use of sensors, the Internet of Things, artificial intelligence, blockchain and a number of other technologies is called the Fourth Industrial Revolution (Industry 4.0) (Krivokapić at al, 2019). Industry 4.0 would not be possible without the use of large amounts of data in business. The European Union (EU) recognizes the importance of data as a resource for economic development, creation of new jobs, competitiveness, innovation and social progress. One of the pillars of the development of the EU economy is the construction of the data economy, the total share of which in 2016 was 300 billion euros (1.99% of European social income) with a tendency to grow in the following years (Krivokapić at al, 2019).

Open data

Open data is data that is publicly available to everyone and can be used for any purpose in any way, without copyright or other restrictions (Dymora at al, 2018). Most often, this term refers to data obtained from public institutions of society, but the term is also used for other types of data (medical data and the like). The open data initiative was created in 2007 when Lessing and his collaborators started the initiative to open the data of Government institutions in the United States of America (USA) in order to achieve transparency and introduce control at work (Ayre & Craner, 2017). In 2013, in the USA, then-President Obama signed an executive order on open data. The decree opens an open data portal, states that openness in government strengthens democracy, promotes the delivery of efficient and effective services to the public and contributes to economic growth. The advantage of open government is the facilitation of information resources, finding, availability and usability of data (Ayre & Craner, 2017).

Proper use of open data can help achieve the following goals (Terzić & Majstorivić, 2019):

- Open data helps governments and citizens to make better decisions based on the availability of more data.
- Users can combine different datasets.
- The openness of data allows researchers to explore trends as well as uncover social and economic problems.
- Open data helps the public sector and institutions to achieve better results in areas such as health, education, public safety, ecology, natural disasters and the like.
- Open data contributes to economic development and helps in business operations.
- It improves the flow of information in the government, improves intersectoral cooperation and contributes to greater transparency.
- The openness of economic data helps to control the spending of public money.
- Government openness accelerates institutional reactions, reduces corruption and helps build new democratic spaces for citizens (Keserű & Kin-Sing Chan, 2015).

Open data is usually created by public institutions. Before being published, data must go through an anonymization process (Dymora at al, 2018). One of the basic requirements that open data must meet is to ensure privacy. Data that is not allowed to be shared is called closed data. The term closed data usually means personal data. Some data may be processed by a limited number of users for the purpose of various research. Such data is called shared data.

Open data must be in a format that allows easy machine processing. Open data formats must enable processing in at least one open format software (opendata portal).

Open data in Serbia

The first available set of open data in Serbia appeared in 2015 in the work of the Ministry of Education, Science and Technological Development, and significant progress has been made since then. The number of publicly available open data sets in 2019 on the open data portal data.gov.rs was over 650 from over 25 institutions (Krivokapić at al, 2019). In April 2023, that number was around 2166 from 111 institutions (Data.gov.rs, 2023a, 2023b). The Law on Electronic Government from 2018 requires public bodies to open data within their jurisdiction (Službeni glasnik RS, 27/2018). The degree of progress of countries in terms of opening data can be monitored on the Global Open Data Index portal (2023). Data are analyzed in 15 categories. Serbia is in 41st place with a degree of openness of 41%. According to the Global Open Data Index, (2023), the highest degree of openness is in the area of public procurement as well as information on the degree of air quality. In four categories, the Government did not open its data, namely:

- election data,
- overview of locations,
- spending the Government's money, and
- ownership of plots.

Open data on traffic accidents

The use and processing of open data creates favorable conditions for the discovery of new knowledge in order to provide answers to important social problems. One of the major problems around the world are traffic accidents that claim more and more lives and cause great material damage. With high-quality data analytics, conclusions can be drawn that could reduce harmful consequences in the future. Saxena & Robila (2021) describes the use of open data in the field of traffic and presents a tool for the analysis of traffic accidents in the territory of the city of New York based on open data analytics. The tool analyzes all the factors that have influenced traffic accidents, visually represents the locations where accidents have occurred, and provides insight into the details in order to draw conclusions with the aim of reducing the number of accidents in the future. Gladivić and Deretić describes the analysis of traffic accidents in the territory of the City of Belgrade (Gladović & Deretić, 2018). At the very beginning, the authors describe a set of open data, and then provide an analysis of the data in Excel. The hypothesis of increased traffic safety in the territory of the City of Belgrade in 2016 compared to 2015 was examined.

Visualization means translating information into a visual context to make it easier to understand. Visualization can be used to create high-quality graphical representations of data, but also to perform exploratory data analysis, EDA. In the paper (Volpi at al, 2014), the authors presented the visual platform Roma Crash Map, which visually presents open data on traffic accidents in 19 municipalities of the city of Rome. A similar project in Serbia was developed by the Observatory of Social Innovation (ODI) through an interactive map based on open data on traffic accidents from 2015 to 2019 sorted by various categories (Opservatorija društvenih inovacija, 2023).

Methodology used in the work

For the purposes of building the traffic accident analysis application, data from the open data portal covering the period from 2015 to January 2023 was used (Open data portal). Datasets are provided in .xlsx format. The description of the columns is given in Table 1.

Table 1 – Open data columns used to build the application
Таблица 1 – Открытые данные, используемые для разработки приложения
Табела 1 – Опис колона отворених података које се користе за израду апликације

Number of the column	Description
1	Traffic accident identification number
2	Police department
3	Police station
4	Date and time
5	Longitude
6	Latitude
7	Kind of traffic accident
8	Type of traffic accident
9	Description of the traffic accident

The application for the automatic analysis of traffic accident data was developed in the Streamlit development environment using the Pandas library. Streamlit is an open source Python library for easily creating web applications for machine learning and data analytics. It provides an intuitive and simple way of working when building applications and does not require knowledge of other web tools. It is characterized by excellent documentation that further facilitates the work (Docs.streamlit.io, 2023).

Streamlit has made it completely simple to create interfaces, display text, visualize data, render widgets, and manage a web application from start to deployment with its practical and highly intuitive application programming interface (Khorasani et al, 2022).

Current code implementation is a feature of the environment that allows the developer to visually track changes to the application every time he makes changes to the program (Konova, 2022). The code can be written in any Python editor. As Python scripts, they are compatible with Git and other version control software. It is also compatible with other Python machine learning libraries such as Keras, Scikit-Learn, NumPy and others. Installation is done through the package management system in Python with the following command, pip install streamlit.

The main feature of this web environment is the simplicity of operation.

Figure 1 illustrates how in just a few lines of code, using the API provided by the framework, one can get a web page that visually presents the data (Docs.streamlit.io, 2023).

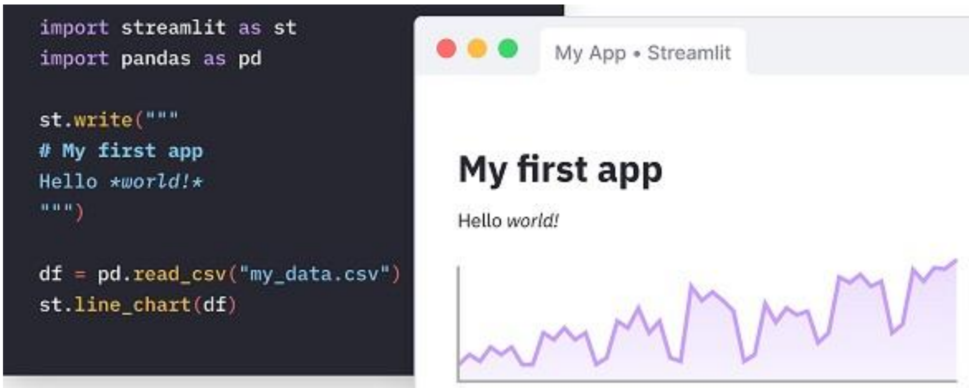


Figure 1 – Web page created in the Streamlit environment (Docs.streamlit.io, 2023)

Рис. 1 – Веб-страница, созданная в среде приложения Streamlit (Docs.streamlit.io, 2023)

Слика 1 – Пример веб-странице креиране у окружењу Streamlit (Docs.streamlit.io, 2023)

Pandas is an open source Python library designed for fast and easy data processing. It is interesting that in terms of the number of questions, the Pandas library has the highest growth trend on the stackoverflow site (Reddit.com, 2020).

It has excellent documentation that allows easy manipulation of tabular data (Pandas.pydata.org, 2023).

Application for automatic analysis of open traffic accident data

The user of this application will be able to get acquainted with the concept of open data and, through the analysis of traffic accident data, gain a clearer picture of the statistical data related to this social problem. The application consists of three pages: Homepage, About_project and Data. The central part of the application is on the Data page, while the remaining two pages are informative and present some functionality of the Streamlit development framework, such as adding images and videos. On the Data page there is a user manual for using the application. The user is required to initially select data for analysis by drag and drop or by using the file manager (Figure 2). The application processes only traffic accident data sets available on the open data portal.

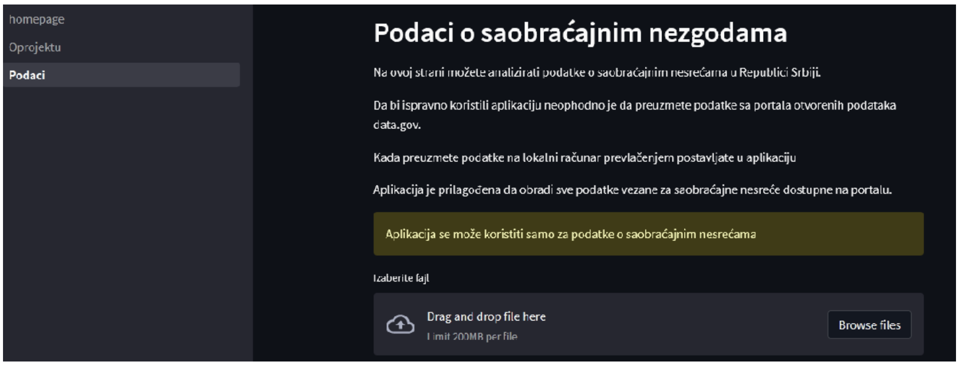
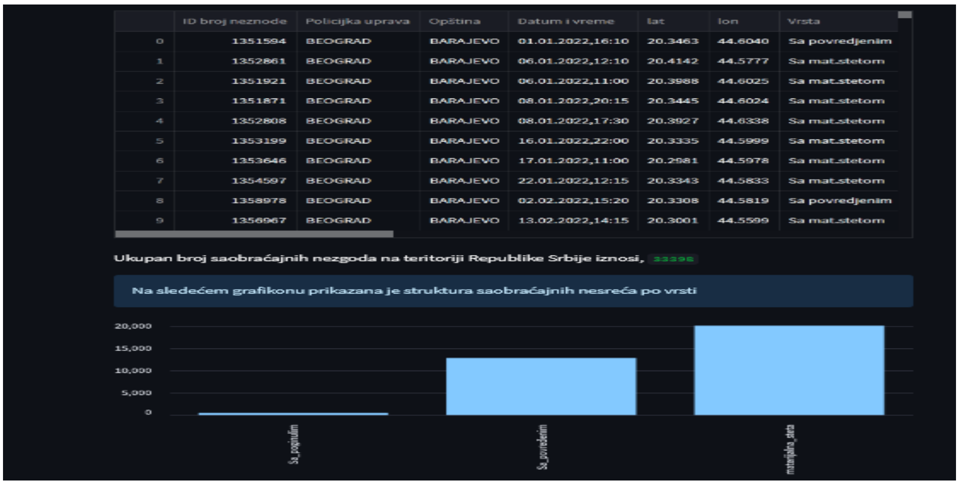


Figure 2 – Image of the central part of the application for automatic processing of traffic accident data (Gavrilović, 2023)
Рис. 2 – Изображение центральной части приложения для автоматической обработки данных о дорожно-транспортных происшествиях (Gavrilović, 2023)
Слика 2 – Слика централног дела апликације за аутоматску обраду података о саобраћајним несрећама (Gavrilović, 2023)

After the user enters data into the application, tabular, numerical and graphic reports on traffic accidents for the selected data set are obtained (Figure 3). In addition to this data, the user can perform appropriate filtering by selecting the police department as well as the type of offense and obtain a tabular display of the data according to the given criteria (Figure 4). At the end of the page, there is a display of traffic accidents on a geographical map (Figure 5). The map has a possibility of enlargement for a more precise insight into the geolocation of the traffic accident. In this way, potentially dangerous places in traffic can be easily identified.

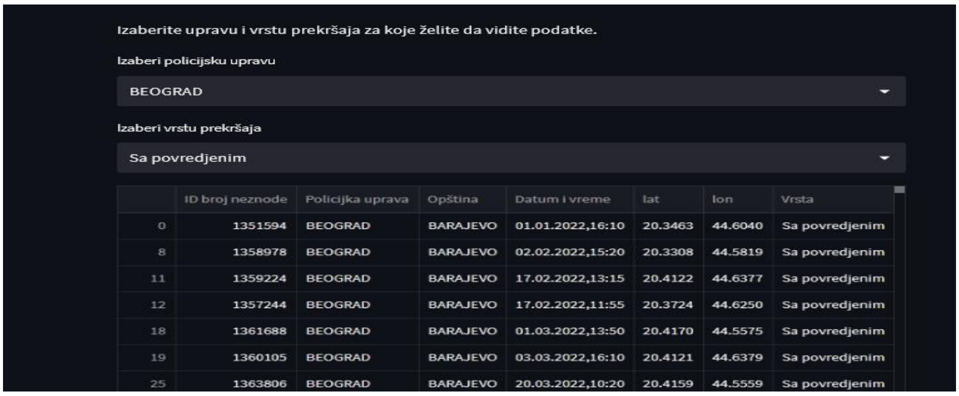


	ID broj neznode	Policijka uprava	Opština	Datum i vreme	lat	lon	Vrsta
0	1351594	BEOGRAD	BARAJEVO	01.01.2022,16:10	20.3463	44.6040	Sa povredjenim
1	1352861	BEOGRAD	BARAJEVO	06.01.2022,12:10	20.4142	44.5777	Sa mat.stetom
2	1351921	BEOGRAD	BARAJEVO	06.01.2022,11:00	20.3988	44.6025	Sa mat.stetom
3	1351871	BEOGRAD	BARAJEVO	08.01.2022,20:15	20.3445	44.6024	Sa mat.stetom
4	1352808	BEOGRAD	BARAJEVO	08.01.2022,17:30	20.3927	44.6338	Sa mat.stetom
5	1353199	BEOGRAD	BARAJEVO	16.01.2022,22:00	20.3335	44.5999	Sa mat.stetom
6	1353646	BEOGRAD	BARAJEVO	17.01.2022,11:00	20.2981	44.5978	Sa mat.stetom
7	1354597	BEOGRAD	BARAJEVO	22.01.2022,12:15	20.3343	44.5833	Sa mat.stetom
8	1358978	BEOGRAD	BARAJEVO	02.02.2022,15:20	20.3308	44.5819	Sa povredjenim
9	1356967	BEOGRAD	BARAJEVO	13.02.2022,14:15	20.3001	44.5599	Sa mat.stetom

Figure 3 – Tabular, numerical and graphic representation of traffic accidents (Gavrilović, 2023)

Рис. 3 – Табличное, числовое и графическое представление дорожно-транспортных происшествий (Gavrilović, 2023)

Слика 3 –Таблична, нумеричка и графичка презентација података о саобраћајним несрећама (Gavrilović, 2023)



	ID broj neznode	Policijka uprava	Opština	Datum i vreme	lat	lon	Vrsta
0	1351594	BEOGRAD	BARAJEVO	01.01.2022,16:10	20.3463	44.6040	Sa povredjenim
8	1358978	BEOGRAD	BARAJEVO	02.02.2022,15:20	20.3308	44.5819	Sa povredjenim
11	1359224	BEOGRAD	BARAJEVO	17.02.2022,13:15	20.4122	44.6377	Sa povredjenim
12	1357244	BEOGRAD	BARAJEVO	17.02.2022,11:55	20.3724	44.6250	Sa povredjenim
18	1361688	BEOGRAD	BARAJEVO	01.03.2022,13:50	20.4170	44.5575	Sa povredjenim
19	1360105	BEOGRAD	BARAJEVO	03.03.2022,16:10	20.4121	44.6379	Sa povredjenim
25	1363806	BEOGRAD	BARAJEVO	20.03.2022,10:20	20.4159	44.5559	Sa povredjenim

Figure 4 – Using filters for data selection (Gavrilović, 2023)

Рис. 4 – Использование фильтров для отбора данных (Gavrilović, 2023)

Слика 4 – Употреба филтера за селекцију података (Gavrilović, 2023)

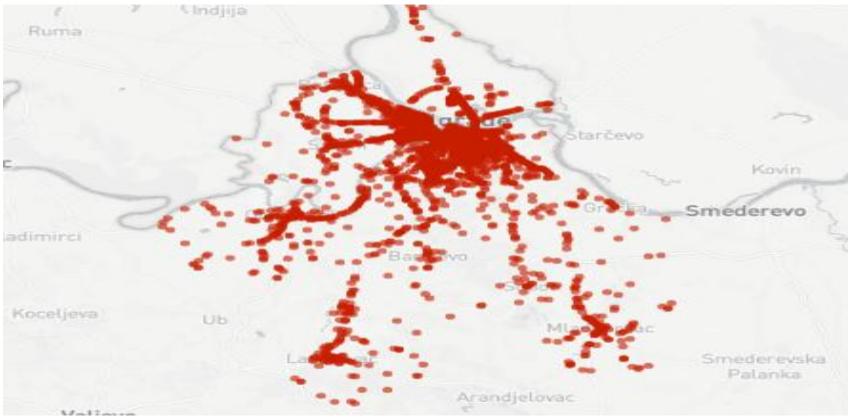


Figure 5 – Traffic accident data represented on a map (Gavrilović, 2023)
Рис. 5 – Данные о дорожно-транспортных происшествиях, представленные на карте (Gavrilović, 2023)
Слика 5 – Представљање података о саобраћајним несрећама на мапи (Gavrilović, 2023)

Comparative analysis of the traffic accidents in the territory of the Police Department of Užice for 2021 and 2022

The practical application of the application for research purposes refers to the analysis of traffic accidents on the territory of the Užice Police Department (Užice PD). The primary goal of the research is to test the hypothesis about whether the analysis of open data on traffic accidents for previous years, and preventive actions, has led to an increase in traffic safety in the territory of the Užice PD. The data was obtained by using the application and selecting the appropriate filters available on it.

A total of 664 traffic accidents were recorded on the territory of the Užice police department in 2021, namely 349 accidents with material damage, 297 traffic accidents with injured persons and 18 accidents with killed persons. Regarding the time interval when the traffic accident occurred, 219 traffic accidents occurred from midnight to 12:00 and 445 from 12:00 to midnight. The most serious forms of traffic accidents are those in which there are injured or killed participants. Traffic accidents with injured persons in 2021 occurred more often after 12:00 (201) than before 12:00 (96). In the period from midnight to 12:00, there were 5 fatal traffic accidents, while in the period from 12:00 to midnight that number was 13. Through graphic interpretation and visualization, it is possible to identify potentially dangerous road routes on the territory of the selected PD. The graphic representation of the geolocations of the accidents with injured persons for the year 2021 on the territory of the Užice PD is shown in Figure 6.

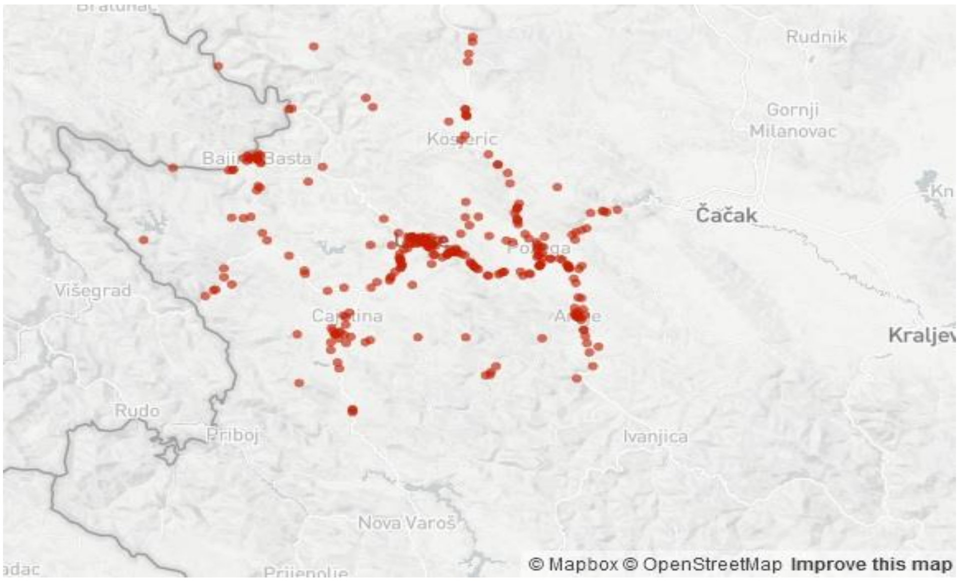


Figure 6 – Geolocations of the traffic accidents with injured persons for the year 2021 (Gavrilović, 2023)
Рис. 6 – Географические координаты дорожно-транспортных происшествий с пострадавшими в 2021 году (Gavrilović, 2023)
Слика 6 – Локације саобраћајних несрећа са повређеним лицима у 2021. години (Gavrilović, 2023)

A graphic representation of the geolocations of the traffic accidents with fatalities in the territory of the Užice PD for the year 2022 is given in Figure 7.

A total of 647 traffic accidents were recorded on the territory of the Užice Police Department in 2022, of which 375 resulted in material damage, 255 resulted in injuries and 17 accidents resulted in fatalities. In the period from midnight to 12:00, 236 traffic accidents were recorded, while in the period from noon to midnight, 411 were recorded. The number of traffic accidents with injured persons until noon in 2022 was 86, while 169 such accidents occurred from noon to midnight. When it comes to accidents in which there were fatalities, they happened more in the afternoon (10) than in the morning (7). The graphic representation of the accidents with injured persons is in Figure 8.

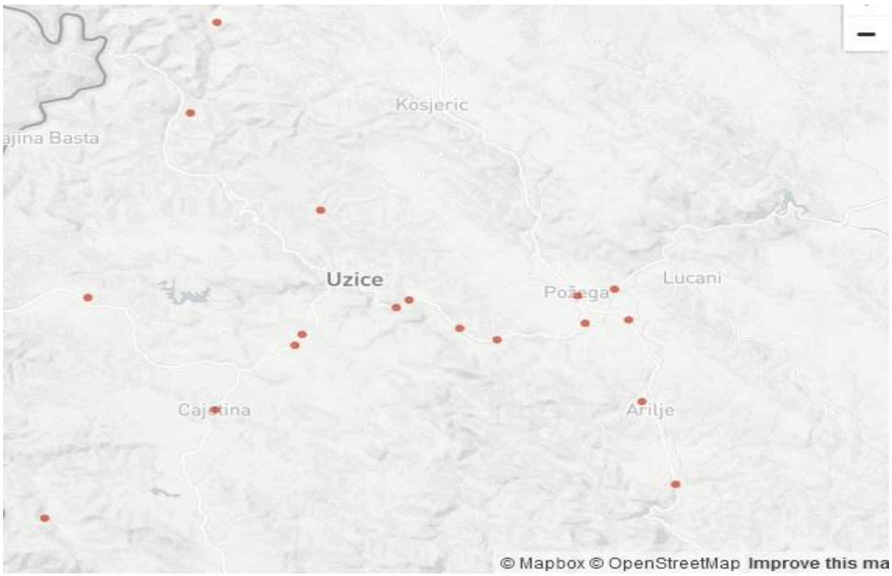


Figure 7 – Geolocations of the fatal traffic accidents for 2021 (Gavrilović, 2023)
Рис. 7 – Географические координаты дорожно-транспортных происшествий со смертельным исходом в 2021 году (Gavrilović, 2023)
Слика 7 – Геолокација саобраћајних несрећа са смртним исходом у 2021. години (Gavrilović, 2023)

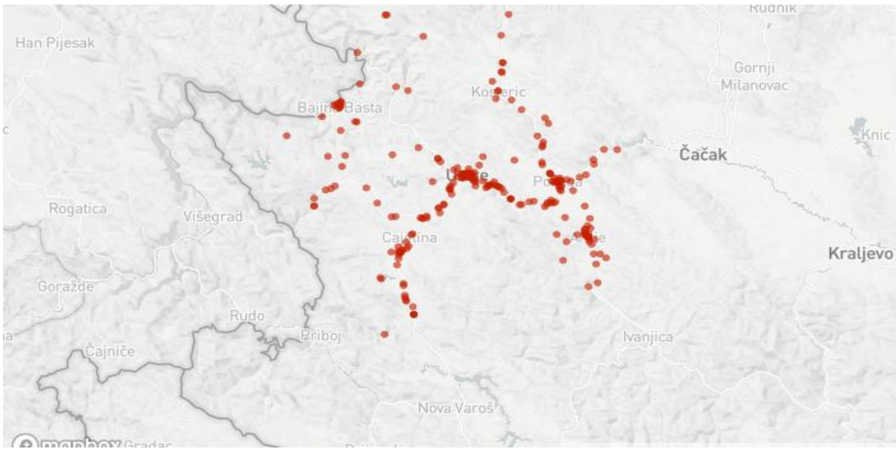


Figure 8 – Geolocations of the traffic accidents with injured persons for the year 2022 (Gavrilović, 2023)
Рис. 8 – Географические координаты дорожно-транспортных происшествий с пострадавшими в 2022 году (Gavrilović, 2023)
Слика 8 – Локације саобраћајних несрећа са повређеним лицима у 2022. години (Gavrilović, 2023)

The graphic representation of the locations of the traffic accidents with fatalities is presented in Figure 9.

Figure 9 – Geolocations of the fatal traffic accidents in 2022 (Gavrilović, 2023)
Рис. 9 – Географические координаты дорожно-транспортных происшествий со смертельным исходом в 2022 году (Gavrilović, 2023)
Слика 9 – Геолокација саобраћајних несрећа са смртним исходом у 2022. години (Gavrilović, 2023)

The analysis of the graphic interpretations in Figure 6 and Figure 8 shows it is noticeable that the largest number of traffic accidents with injured persons in the territory of the Užice Police Department occurs on two road directions, Užice-Čajetina and Užice-Požega. Apart from these main road routes, there is a noticeable problem with safety on the Požega-Arilje and Požega-Kosjerić roads, as well as on the branch of the road that leads from the town of Sušica to the Kotroman border crossing.

When the geolocations of the traffic accidents with dead participants in Figures 7 and 9 are compared, the conclusion is similar to the previous one. The largest number was recorded on the highway routes Užice-Čajetina and Užice-Požega. The comparison of the data from Figures 7 and 9 reveals a noticeable decrease in the number of traffic accidents with a fatal outcome in 2022 on the Užice-Požega road, while there is a slight increase on the Užice-Čajetina road.

The structure of traffic accidents for 2021 and 2022 by the time period when they occurred is presented in Table 2.

Table 2 – Percentage of accidents in relation to the time when they occurred
Таблица 2 – Процентный обзор дорожно-транспортных происшествий по годам
Табела 2 – Процентуални приказ саобраћајних несрећа по времену када су се догодиле

Percentage of traffic accidents in relation to the time when they occurred	00h -12h	12h - 00h
2021	32.98%	67.02%
2022	36.47%	63.53%

From the Table 2 data, it is noticeable that a greater number of traffic accidents occur in the afternoon. Regarding the intervals by year, the number of traffic accidents from midnight to noon is percentageally higher in 2022 than in 2021.

Table 3 shows the data on traffic accidents for 2021 and 2022.

Table 3 – Comparative presentation of traffic accidents by year
Таблица 3 – Сравнительный анализ дорожно-транспортных происшествий по годам
Табела 3 – Упоредна анализа саобраћајних несрећа по годинама

Number of traffic accidents by category	With material damage	With injured persons	With dead persons	Total
2021	349	297	18	664
2022	375	255	17	647
In %	+7.45%	-14.14%	-5.56%	-2.56%

When it comes to traffic accidents with material damage, there was an increase of 7.45%, while the number of traffic accidents with injured persons decreased by 14.4%. There was also a decrease in the number of fatal traffic accidents by 5.56%. Regarding the absolute numbers of traffic accidents, the total number of traffic accidents is lower by 2.56%, so we can accept the hypothesis that there has been an increase in traffic safety in the territory of the Užice PD.

The conclusions obtained from the statistical analysis of the data should be taken with a grain of salt due to potential shortcomings in the method of collection, recording and uneven registration (Gladović& Deretić, 2018).

Conclusion

This work shows the possibility of using the Streamlit framework for creating an application for processing open data. The work begins with a short introduction, then the concept of open data is explained and the previous works based on open data on traffic accidents are presented. The main part of the paper is a description of the web application for the analysis of traffic accidents in the Republic of Serbia and its practical application to the analysis of traffic accidents in the territory of the Užice PD. The aim of the work is to get acquainted with open data and the functional possibilities of the Streamlit development environment through the analysis of the application operation. Using the application enables a review of data on traffic accidents according to various criteria, which facilitates the review by researchers and services in charge of traffic safety. The analysis of the data for the Užice Police Department showed that there was an increase in the general level of traffic safety in 2022 compared to 2021. The visualization identified road routes where there were the most accidents with injured and dead persons and where preventive control measures should potentially be strengthened. The application presented in the paper has room for upgrading in the future, by introducing additional functionalities, in order to make the work even easier for professionals for whom it is intended.

References

Ayre, L.B. & Craner, J. 2017. Open Data: What It Is and Why You Should Care. *Public Library Quarterly*, 36(2), pp.173-184. Available at: https://doi.org/10.1080/01616846.2017.1313045.

Daley, S. 2022. Data Science What is Data Science? A Complete Guide. *Builtin.com*, 17 August [online]. Available at: https://builtin.com/data-science [Accessed: 10 March 2023].

-Data.gov.rs (Portal otvorenih podataka Vlade Republike Srbije). 2023a. *Otvoreni podaci* [online]. Available at: https://data.gov.rs/sr/discover/ (in Serbian) [Accessed: 10 March 2023].

-Data.gov.rs (Portal otvorenih podataka Vlade Republike Srbije). 2023b. *Podaci o saobraćajnim nezgodama po POLICIJSKIM UPRAVAMA i OPŠTINAMA* [online]. Available at: https://data.gov.rs/sr/datasets/podatsi-o-saobratshajnim-nezgodama-po-politsijskim-upravama-i-opshtinama/ (in Serbian) [Accessed: 10 March 2023].

-Docs.streamlit.io. 2023. *Streamlit documentation* [online]. Available at: https://docs.streamlit.io/ [Accessed: 10 March 2023].

Dymora, P., Mazurek, M. & Kowal, B. 2018. Open data – an introduction to the issue. In: *ITM Web of Conferences 21, 00017 (2018)*. Available at: https://doi.org/10.1051/itmconf/20182100017.

Gavrilović, B. 2023. *Aplikacija za automatsku obradu otvorenih podataka o saobraćajnim nesrećama* [online]. Available at: https://brankogavrilovic-automatska-obrada-homepage-r3ltns.streamlit.app/ (in Serbian) [Accessed: 03. March 2023].

Gladović, P.V. & Deretić, N.N. 2018. Open data and databases in analysis of traffic accidents in Belgrade. *Tehnika*, 73(2), pp.247-253 (in Serbian). Available at: https://doi.org/10.5937/tehnika1802247G.

-Global Open Data Index. 2023. *Place overview* [online]. Available at: https://index.okfn.org/place.html [Accessed: 10 March 2023].

Keserű, J. & Kin-Sing Chan, J. 2015. The Social Impact of Open Data. In: *3rd International Open Data Conference (IODC)*, Ottawa, Canada, May 28-29.

Khorasani, M., Abdou, M. & Hernández Fernández, J. 2022. Streamlit Basics. In: *Web Application Development with Streamlit*. Berkeley, CA: Apress. Available at: https://doi.org/10.1007/978-1-4842-8111-6_2.

Konova, P.S. 2022. Streamlit library as a tool for processing and visualization of big data. *Stolypin messenger*, 3(2) [online]. Available at: https://stolypin-vestnik.ru/wp-content/uploads/2022/08/59.pdf (in Russian) [Accessed: 10 March 2023]. (In the original: Конова, П.С. 2022. Библиотека streamlit как инструмент обработки и визуализации больших данных. *Столыпинский вестник*, 3(2) [онлайн]. Доступно на: https://stolypin-vestnik.ru/wp-content/uploads/2022/08/59.pdf (in Russian) [Дата обращения: 10 Март 2023].)

Krivokapić, Đ., Adamović, J., Milošević, F. & Kosmina, K. 2019. *Vodič kroz otvorene podatke*. Belgrade: United Nations Development Programme [online]. Available at: https://data.gov.rs/_themes/govrs/doc/vodic-kroz-otvorene-podatke_cirilica.pdf (in Serbian) [Accessed: 10 March 2023]. ISBN: 978-86-7728-259-2.

-Opservatorija društvenih inovacija. 2023. *O vizuelizaciji: gde se dešavaju saobraćajne nezgode* [online]. Available at: https://data.odi.rs/rsnezgode/ (in Serbian) [Accessed: 10 March 2023].

-Pandas.pydata.org. 2023. *Pandas documentation* [online]. Available at: https://pandas.pydata.org/docs/ [Accessed: 10 March 2023].

-Reddit.com. 2020. *Stack overflow traffic to questions about selected python packages* [online]. Avaiable at: https://www.reddit.com/r/Python/comments/jogwc5/stack_overflow_traffic_to_questions_about/ [Accessed: 10 March 2023].

Saxena, A. & Robila, S.A. 2021. Analysis of the New York City's Vehicle Crash Open Data. In: *2021 IEEE International Conference on Big Data (Big Data)*, Orlando, FL, USA, pp.6017-6019, December 15-18. Available at: https://doi.org/10.1109/BigData52589.2021.9672012.

-Službeni glasnik RS. 27/2018. *Zakon o elektronskoj upravi*. Belgrade: JP „Službeni glasnik“ (in Serbian).

Terzić, R. & Majstorović, M. 2019. Open data concept, its application and experiences. *Vojnotehnički glasnik/Military Technical Courier*, 67(2), pp.347-364. Available at: https://doi.org/10.5937/vojtehg67-19935.

Volpi, V., Ingrosso, A., Pazzola, M., Opromolla, A. & Medaglia, C.M. 2014. Roma Crash Map: An Open Data Visualization Tool for the Municipalities of Rome. In: Yamamoto, S. (Eds.) *Human Interface and the Management of Information. Information and Knowledge in Applications and Services. HIMI 2014*. *Lecture Notes in Computer Science*, 8522. Cham: Springer. Available at: https://doi.org/10.1007/978-3-319-07863-2_28.

Сравнительный анализ дорожно-транспортных происшествий на территории города Ужице за 2021 и 2022 годы с использованием открытых данных и приложения Streamlit

Бранко М. Гаврилович[а], *Елена* Митрович[б]

[а] Экономический колледж, г.Ужице, Республика Сербия, **корреспондент**

[б] Университет Пасау, факультет факультет математики и вычислительной техники, г.Пасау, Федеративная Республика Германия; Научно-исследовательский институт искусственного интеллекта Сербии, г.Нови-Сад, Республика Сербия

РУБРИКА ГРНТИ: 50.41.21 Системы управления базами данных (СУБД), 50.53.17 Автоматизация сбора и обработки данных научного эксперимента

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: С развитием информационных технологий, интернета и социальных сетей объем собираемых данных год от года растет с огромной скоростью. Обработка и анализ данных становятся необходимостью, без которых невозможно принимать качественные бизнес-решения. С развитием науки о данных (Data Science) были также разработаны инструменты для обработки неструктурированных данных. Открытые данные представляют собой общедоступные данные, обработка которых позволяет получать новые знания. Цель данной работы − представить возможность использования открытых данных в исследовательских целях и их обработки с помощью среды приложения Streamlit.

Методы: В данной статье представлен Streamlight фреймворк языка программирования Python и его функциональность на основе анализа веб-приложения для анализа данных. В качестве тематического исследования представлен сравнительный анализ данных о дорожно-транспортных происшествиях на территории г. Ужице за 2021 и 2022 годы по данным районного управления МВД.

Результаты: Приложение Streamlit использовалось для автоматического анализа открытых данных о дорожно-транспортных происшествиях на территории Республики Сербия с целью обработки данных и проверки гипотезы о том, что такой метод повысит безопасность дорожного движения на территории районного управления внутренних дел по г.Ужице.

Выводы: Данное исследование показывает возможности использования фреймворка Streamlight в разработке приложения для обработки открытых данных.

Ключевые слова: Описательная аналитика, открытые данные, Streamlit, Pandas, Python, дорожно-транспортные происшествия.

Упоредна анализа саобраћајних несрећа на територији града Ужица у 2021. и 2022. години применом отворених података и Streamlit апликације

Бранко М. Гавриловић[а], *Јелена* Митровић[б]

[а] Средња економска школа, Ужице, Република Србија, **аутор за преписку**

[б] Универзитет Пасау, Факултет за рачунарство и математику, Пасау, Савезна Република Немачка; Истраживачко-развојни институт за вештачку интелигенцију Србије, Нови Сад, Република Србија

ОБЛАСТ: рачунарске науке, информационе технологије
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Са развојем информационих технологија, интернета и друштвених мрежа, количина прикупљених података расте великом брзином. Њихова обрада и анализа постаје неопходност без које се не могу доносити квалитетне пословне одлуке. Са развојем науке о подацима (Data Science) развијени су и алати за обраду неструктурираних података. Отворени подаци су јавно доступни, а њихова обрада омогућава стицање нових знања. Циљ рада јесте представљање могућности коришћења отворених података у истраживачке сврхе, као и њихове обраде кроз Streamlit развојно окружење.

Методе: У раду је представљен Streamlit оквир програмског језика Python и његова функционалност кроз анализу веб-апликације за анализу података. Као студија случаја приказана је упоредна анализа података о саобраћајним незгодама на територији ПУ Ужице у 2021. и 2022. години.

Резултати: Streamlit апликација биће коришћена за аутоматску анализу отворених података о саобраћајним незгодама у Републици

Србији ради обраде података и тестирања хипотезе о томе да ли је дошло до повећања безбедности саобраћаја на територији ПУ Ужице.

Закључак: У раду је предочена могућност коришћења Streamlit-a за креирање апликације за обраду отворених података.

Кључне речи: дескриптивна аналитика, отворени подаци, Streamlit, Pandas, Python, саобраћајне незгоде.

Paper received on / Дата получения работы / Датум пријема чланка: 13.03.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 12.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 14.06.2023.

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2023, Vol. 71, Issue 3

Monitoring and analysis of air quality and meteorological parameters on the construction site by the IoT

Lazar B. Milivojević

The University "Union - Nikola Tesla", Faculty of Construction Management, Belgrade, Republic of Serbia,
e-mail: lmilivojevic@unionnikolatesla.edu.rs,
ORCID iD: https://orcid.org/0009-0009-7582-0605

DOI: 10.5937/vojtehg71-44315; https://doi.org/10.5937/vojtehg71-44315

FIELD: computer science, construction industry
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The construction industry is one of the main producers of dust, greenhouse gases and air pollutants. Effective operation and management of construction site operations can significantly reduce projects' carbon footprints and other environmental impacts. Through the cooperation of a scientific and research institution and a construction company, the real-time monitoring of air quality at a construction site was implemented using IoT technologies.

Methods: An IoT-based system framework that integrates a distributed sensor network to collect real-time data and demonstrates air quality at a construction site was implemented. Different types of sensors were used to collect data related to NO2, PM2.5, and PM10 particles, as well as meteorological parameters – wind speed and direction, humidity, pressure, and temperature.

Results: The results of real-time measurements provide a picture of the state of air pollution at the construction site and the connection with construction activities that can be managed in order to reduce the concentration of polluting gases and suspended particles. Through on-site monitoring of a construction site in Belgrade City, this study found that the dust level due to construction activities is relatively high.

Conclusion: It can be concluded that the construction activity had a significant impact on the air quality in the construction surrounding areas. Regarding the main factors affecting the building construction dust emission, the correlations show that building construction dust emission was not significantly correlated with meteorological factors.

Key words: construction site, PM concentration, correlation, meteorology.

Introduction

With the looming consequences of climate changes, sustainability measures, including quantifying the amount of air pollution during various types of activities, have become an important goal in all branches of the economy, including the construction industry. All construction sites generate high levels of pollution over a long period of time. The construction industry is one of the main producers of greenhouse gases (GHG) with a share of about 12% of the total world emissions. According to official figures from the Delhi Pollution Control Committee (DPCC), 30% of air pollution by dust is caused by emissions from construction sites. Various construction activities such as excavation, diesel engine operation, demolition, burning and working with toxic materials contribute to air pollution. The main factor that contributes to air pollution with nitrogen and sulfur oxides during construction projects is the use of heavy equipment, ie., machines (excavators, loaders, bulldozers, etc.) as a result of burning the fuel used by these machines. PM pollution is mainly attributed to excavation work. A significant source of PM 2.5 particles on construction sites are exhaust gases from diesel engines and diesel generator sets, vehicles and heavy equipment. Harmful substances from oils, glues, solvents, paints, treated woods, plastics, cleaning agents, and other hazardous chemicals widely used on construction sites also contribute to air pollution.

In the Balkans, Serbia is the leader in the construction industry which is growing year by year. In August 2022, 2,562 building permits were issued. This construction trend promises a further significant increase in the concentration of greenhouse gases and other pollutants. For these reasons, it is primarily necessary to introduce monitoring of polluting gases and PM particles in real time in order to propose measures to reduce the concentration of polluting gases and PM particles through insight into the amount of pollution present and depending on the atmospheric conditions.

Although emissions of harmful substances in the construction industry are becoming more and more significant due to the accelerated trend of construction in Serbia, a real-time emission monitoring tool, essential to help construction teams avoid excessive emissions of harmful substances, has not yet been introduced to the construction sites in the Republic of Serbia. The considerable importance of the application of this system and the implementation of this type of research is for the health of employees at construction sites who often have health problems due to the working conditions, i.e., the poor air quality at construction sites, which sometimes reaches such a bad quality that it endangers the lives of workers.

Particulate matter (PM) is one of the most common air pollutants globally as well as nitrogen oxides (NOx), photochemical oxidants including ozone (O3), carbon monoxide (CO), lead (Pb), and sulfur dioxides (SO2). (EPA, 2022)

In the last few years, research has been done on the effects on dust concentration at construction sites, with a focus on PM10 and PM2.5 (De Moraes et al, 2016; Hassan et al, 2016; Yan et al, 2019). It was found that there are a number of factors that influence the concentration of PM particles at construction sites. Certainly, the surroundings of construction sites represent a source of certain emissions that are transported and registered on construction sites themselves, independently of the activities on construction sites. These are so-called background emissions. When it comes to meteorological factors, several studies have been done on the connection between meteorological parameters and the concentration of polluting substances (including PM particles), and there are conflicting views on that topic. Some authors (Araújo et al, 2014) believe that meteorology has an extremely important influence on the concentration of PM particles at the construction site, although due to the lack of concentration data, they failed to develop a model for the dependence of PM particle concentrations on meteorological parameters. According to some other authors (Zhang et al, 2010), dust emissions from construction sites have significant seasonal changes, which was also confirmed by other researchers in their research (Zhao et al, 2010). This again indicates a strong relationship between the concentration of PM particles and meteorological parameters. In some research (Luo, 2017; Wei et al, 2022) that also studied the relationship between construction works and meteorological parameters, it was concluded that PM particles are highly positively correlated with wind speed and relative air humidity, and weakly with temperature. In addition to excavation work, internal works on buildings also have a certain contribution to emissions. Kinsey et al (2004) found that vehicles leaving a construction site can carry a large amount of dust and sediment to nearby roads, leading to the rise of secondary dust. Azarmi et al (2014) carried out a detailed monitoring of certain phases of work on the construction site, such as concrete mixing, drilling and cutting. PM10, PM2.5, and PM0.1 concentrations of PM particles during drilling and cutting activities were up to 14 times higher than background concentrations. Moraes et al. (2016) focused on monitoring the concentration of particulate matter (PM10) generated from concrete and masonry in construction activities. These and similar studies have shown that certain phases and activities during work on construction sites are an important factor that affects the concentration of PM particles. (Font et al, 2014).

The goal of this research is a deeper and more detailed analysis of the relationship between the concentrations of PM particles on the construction site that are emitted due to excavation work and meteorological parameters. The data analysis was done to check the possibility of applying artificial intelligence to predictions of the concentration of PM particles depending on weather conditions.

Materials and methods

The experiment, which consisted of measuring the concentrations of suspended particles PM2.5 and PM10, then NO2, as well as meteorological parameters (pressure, temperature, humidity, speed and wind direction) was carried out at one construction site in Belgrade (Fig. 1) during 15 days in July 2022, from the first to the fifteenth of July. The excavation zone is located west of the location of the measuring station, while additional sources of emissions on the construction site, such as waste, carpentry and reinforcement works, are placed on the north from the monitoring device on the constructin site. Fig. 1 shows the distances of individual emission sources from the measuring station. Emissions from other sources come from the south and east direction and can be treated as background emissions.

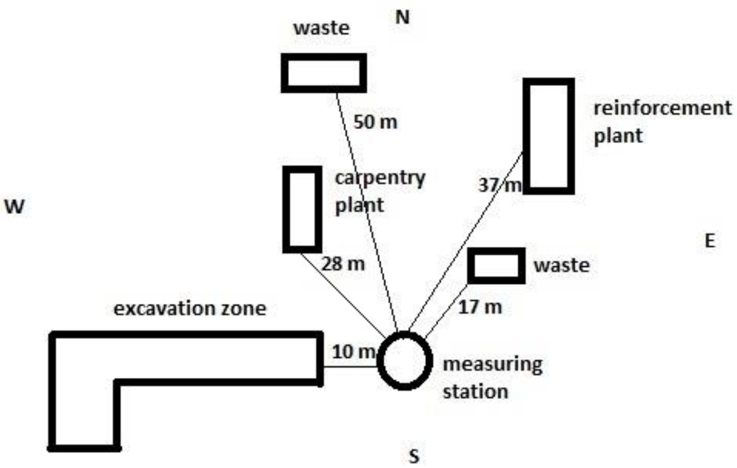


Figure 1 – Sketch of the construction site with the marked positions of the measuring device, the excavation zone, as well as other potential sources of emissions
Рис. 1 – Эскиз строительной площадки с отмеченными местами расположения измерительного прибора, зоны выемки грунта, а также других возможных источников выбросов
Слика 1 – Скица градилишта са обележеним положајима мерног уређаја, зоне ископа, као и других потенцијалних извора емисија

During all fifteen days, two electrically-powered machines were working in the excavation area. All days except Sunday, work was done from 13:00 to 17:00. The waste was taken away by truck every day.The devices used were of a sensor type and the results were recorded every 5 minutes. The RS-MG111-WIFI-1 is an air environment multi-element transmitter. It is used to detect NO2, PM2.5, and PM10. The transmitter adopts the original imported sensor and control chip, which has the characteristics of high precision, high resolution, and good stability. Using WIFI network transmission, it is directly connected to the on-site WIFI network, and the connection is convenient. With the free monitoring platform software or the free IoT cloud platform, it directly formed an online Integrated air environment monitoring system, widely used in building HVAC, building energy saving, smart home, schools, hospitals, airport stations, and other places. Another device is the CC-M12 weather station: an anemometer (WD, WS), temperature, pressure and humidity with RH&T and 4G communication. The devices are portable (with the possibility of installation outdoors and indoors). Such a system allows the manager of the construction site and the company to have a detailed insight into the quality of the environment in real time. In doing so, sources of harmful gas emissions are identified from three main activities in construction: earthworks, transport, and interior works. Different types of sensors were used to collect data related to NO2, PM2.5, PM10 particles, as well as data related to meteorological parameters – wind speed and direction, humidity, pressure and temperature. The web and mobile application provides data visualization (map, list, chart), notifications/alarms when values are outside the defined range, algorithms for data processing, export to csv file. SPSS 23.0 statistical software was used for data analysis in this study.

Results and discussion

The measurement results are shown in Table 1. The results are given as Full Day results (FD), measurement results during the total time, 24 hours a day, for all 15 days, as well as Working Hours results (WH) that show the separated working hours from 7 a.m. to 5 p.m. on weekdays (Monday to Saturday).

By monitoring the concentration of polluting substances, three sets of data were obtained, including PM2.5, PM10, and NO2.

From the results shown, it can be seen that the PM2.5 concentrations ranged from 1 to 133 μg/m^3 throughout the day, i.e., in a period of 24 hours a day, while during working hours they ranged from 1 to 71 μg/m^3. The average value of the PM2.5 concentration for all 15 days was 15.301 µg/m^3 during the whole day's observation, while during working hours it was 14.66 µg/m^3. For all 15 days, the average daily concentrations of PM2.5 were, respectively: 26.46, 14.69, 21.06, 26.87, 27.09, 15.76, 15.16, 16.55, 11.66, 7.26, 5.75, 9.38, 8.36, 10.20, and 15.26 µg/m^3.

Table 1 – Basic statistical analysis of the measured parameters
Таблица 1 – Базовый статистический анализ измеряемых параметров
Табела 1 – Основна статистичка анализа мерених параметара

	PM2.5 (µg/m^3)	PM10 (µg/m^3)	NO2 (µg/m^3)	p (kapa)	T (°C)	hum (%)	v (m/s)
FD av	15.301	16.811	94.243	1004.78	25.192	51.030	0.354
FD SD	9.5752	11.155	131.989	2.618	6.401	18.534	0.698
FD min	1	1	0	999	12.4	18.1	0
FD max	133	143	510	1010	46.2	98.3	17.8
WH av	14.660	16.0597	167.741	1004.977	28.600	20.2	0.467
WH SD	9.147	10.577	144.859	2.835	5.556	13.749	0.574
WH min	1	2	0	999	15.2	91.1	0
WH max	71	82	510	1010	41.1	40.696	3.2

From the results shown, it can be seen that the PM2.5 concentrations ranged from 1 to 133 µg/m^3 throughout the day, i.e., in a period of 24 hours a day, while during working hours they ranged from 1 to 71 µg/m^3. The average value of the PM2.5 concentration for all 15 days was 15.301 µg/m^3 during the whole day's observation, while during working hours it was 14.66 µg/m^3. For all 15 days, the average daily concentrations of PM2.5 were, respectively: 26.46, 14.69, 21.06, 26.87, 27.09, 15.76, 15.16, 16.55, 11.66, 7.26, 5.75, 9.38, 8.36, 10.20, and 15.26 µg/m^3.

The PM10 concentrations ranged from 1 to 143 µg/m^3 throughout the day, i.e., in a period of 24 hours a day, while during working hours they ranged from 2 to 82 µg/m^3. The average value of the concentration for all 15 days was 16.811 µg/m^3 during the whole day of observation, while during working hours it was 16.06 µg/m^3. For all 15 days, the average daily concentrations of PM10 were, respectively: 29.18, 16.22, 23.05, 30.21, 30.15, 16.97, 16.04, 17.50, 12.69, 7.98, 6.48, 10.55, 9.11, 11.08, and 16.94 µg/m^3.

It can be noted that the highest values of PM10 and PM2.5 particle concentrations were during the night hours, which can be attributed to stabilization of the atmosphere.

According to the WHO limits, PM2.5 should not exceed 5 µg/m3 annual mean, or 15 µg/m3 24-hour mean while PM10 should not exceed 15 µg/m3 annual mean, or 45 µg/m3 24-hour mean. Analyzing the average 24-hour values for PM2.5 and PM10, it can be concluded that PM2.5 represents a far greater health hazard due to far higher values compared to the prescribed daily limits. It can be observed that more than 50% of days, including non-working days, PM2.5 exceed the permissible 24-hour value according to the WHO standards, which is not the case with PM10.

The NO2 concentrations ranged from 0 to 510 µg/m^3 throughout the day, that is, during the 24-hour period, as well as during working hours. The average value for all 15 days was 167.741 µg/m^3 during the whole day of observation, while during working hours it was 94.243 µg/m^3. A significant increase in NO2 concentration can be observed at the construction site during working hours. About 70% is a higher average daily value during 10 working hours compared to all 24 hours.

The impact on the concentration of NO2 can be explained by the transport of waste that was taken to the construction waste disposal site by truck every day, but also by the impact of traffic from nearby roads.

By monitoring meteorological data, five sets of meteorological data were obtained, including wind speed and direction, temperature, humidity, and atmospheric pressure.

The pressure ranged from 999 to 1010 kPa throughout the day, i.e., in a period of 24 hours a day as well as during working hours. The average value for all 15 days was 1004.977 kPa during whole-day observation, while during working hours it was 1004.78 kPa.

Humidity ranged from 18.1 to 98.3% throughout the day, i.e., in a period of 24 hours a day, while during working hours it ranged from 40.696 to 91.1%. The average value for all 15 days was 51.03% during whole-day observation, while during working hours it was 20.2%.

The temperature ranged from 12.4 to 46.2°C throughout the day, i.e., in a period of 24 hours a day, while during working hours it ranged from 15.2 to 41.1°C. The average value for all 15 days was 25.192 °C during whole-day observation, while during working hours it was 28.6°C.

The wind speed ranged from 0 to 24.8 m/s throughout the day, i.e., in a period of 24 hours a day, while during working hours it ranged from 0 to

3.2 m/s. The average value for all 15 days was 0.354 m/s during the whole day of observation, while during working hours it was 0.467 m/s.

Apart from the basic statistical analysis (Table 1), a correlation analysis was done between the PM concentration and the meteorological data. Table 2 shows that the concentrations of PM10 and PM2.5 were not significantly correlated with any meteorological factor.

Table 2 – Values of the linear correlation coefficient among the measured parameters
Таблица 2 – Значения коэффициента линейной корреляции между измеряемыми параметрами
Табела 2 – Вредности линеарног коефицијента корелације између мерених параметара

	PM2.5	p	hum	T	v
PM10	0.987	-0.092	0.299	0.201	0.003
PM2.5	1	-0.103	0.297	0.236	0.008
p		1	0.053	-0.416	-0.989
hum			1	-0.660	-0.030
T				1	0.326

A very high correlation between PM2.5 and PM 10 can be observed, indicating their same origin. The correlation between PM particles and the meteorological parameters shows a small value that is insufficient for the application of meteorological parameters for predictive purposes using some form of artificial intelligence such as ANN. The highest correlation, although lower than 0.3, is between PM particles, humidity, and temperature.

The reasons that led to this result could be that construction dust is affected by many factors. Construction activities are a direct factor that creates construction dust and have a major impact on construction dust much more than meteorological factors. During the monitoring period, meteorological factors did not change too much; in this way, the influence of meteorological factors on construction dust can somewhat be eliminated. Precipitation is the main factor influencing dust. Therefore, it can be considered that the emission of construction dust is not significantly related to any meteorological factor when it does not change too much. To some extent, it is in accordance with the conclusions of the urban PM10 and PM2.5 research (Tian et al, 2014).

Fig. 2 shows the relationship between the concentration of PM10 and PM2.5 particles and the direction of wind. The Figure shows the wind directions in degrees from 0 to 360° on the x-axis. On the y-axis, PM2.5 and PM10 are represented by two different colors. A high degree of correlation between PM particles can be observed, but also that the concentrations of PM2.5 and PM10 particles are increased when the wind takes the direction of 0°, i.e., blows from the north, then 90°, from the east, while other wind directions are followed by lower concentrations of PM10 and PM2.5 particles. These facts coincide with the position of waste dosposal.

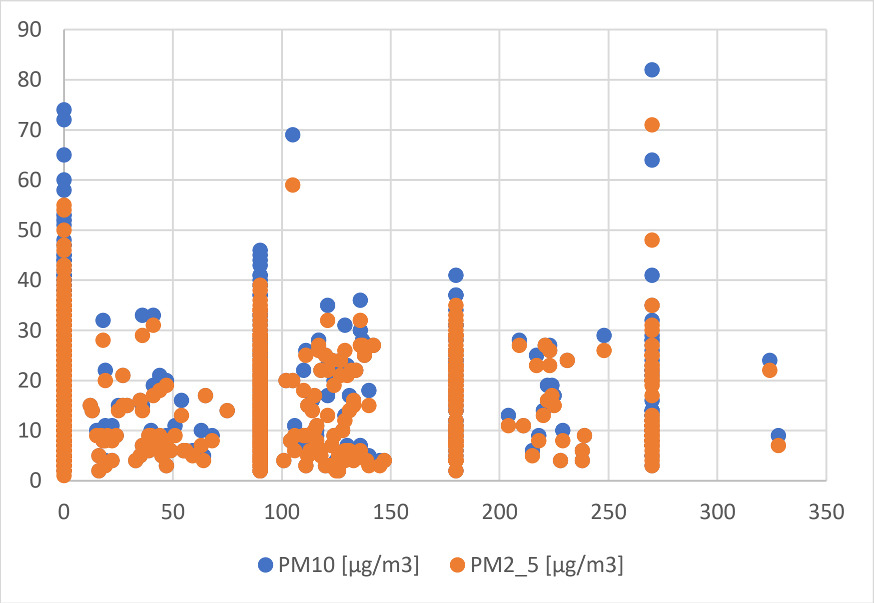


Figure 2 – Dependence of the concentration of PM10 and PM2.5 particles on the construction site on the wind direction
Рис. 2 – Зависимость концентрации частиц PM10 и PM2,5 на строительной площадке от направления ветра
Слика 2 – Зависност концентрације честица ПМ10 и ПМ2,5 на градилишту од правца ветра

Conclusion

The data of meteorological and construction intensity were collected to determine the main factors affecting the construction dust emission, which can provide a basis for reducing the impact of dust generated by construction activities on the surrounding area. The main conclusions of the article are as follows:

Through on-site monitoring of a construction site in Belgrade City, this study found that the dust emission level of construction activities is relatively high. The average PM10 concentration was 16.42 µg/m^3 and the PM2.5 concentration was 8.37 µg/m^3. Analyzing the average 24-hour values for PM2.5 and PM10, it can be concluded that PM2.5 represents a far greater health hazard due to far higher values compared to the prescribed daily limits. In addition, compared with the upwind direction concentrations, the construction site makes PM10 and PM2.5 downwind direction concentrations increased by around 70% and 35%, respectively, which indicates that the construction activity had a significant impact on the air quality in the construction surrounding areas.

Regarding the main factors affecting the building construction dust emission, the results show that building construction dust emission was not significantly correlated with any single meteorological factor when it did not change too much.

Considering a very low correlation between the concentration of PM particles and the meteorological parameters, the possibility of applying ANN for the purpose of creating a prediction model is excluded. A further subject of research will be the application of machine learning in the development of a predictive model that would aim at smart management of the construction site while taking into account the quality of the working and living environment.

References

Araújo, I.P.S., Costa, D.B. & De Moraes, R.J.B. 2014. Identification and Characterization of Particulate Matter Concentrations at Construction Jobsites. *Sustainability,* 6(11), pp.7666-7688. Available at: https://doi.org/10.3390/su6117666.

Azarmi, F., Kumar, P. & Mulheron, M. 2014. The exposure to coarse, fine and ultrafine particle emissions from concrete mixing, drilling and cutting activities. *Journal of Hazardous Materials*, 279, pp.268-279. Available at: https://doi.org/10.1016/j.jhazmat.2014.07.003.

De Moraes, R.J.B., Costa, D.B. & Araújo, I.P.S. 2016. Particulate Matter Concentration from Construction Sites: Concrete and Masonry Works. *Journal of Environmental Engineering,* 142(11). Available at: https://doi.org/10.1061/(ASCE)EE.1943-7870.0001136.

-EPA – United States Environmental Protection Agency. 2022. *Criteria Air Pollutants* [online]. Available at: https://www.epa.gov/criteria-air-pollutants#sel [Accessed: 02 April 2023].

Font, A., Baker, T., Mudway, I.S., Purdie, E., Dunster, C. & Fuller, G.W. 2014. Degradation in urban air quality from construction activity and increased traffic arising from a road widening scheme. *Science of The Total Environment,* 497-498, pp.123–132. Available at: https://doi.org/10.1016/j.scitotenv.2014.07.060.

Hassan, H.A., Kumar, P. & Kakosimos, K.E. 2016. Flux estimation of fugitive particulate matter emissions from loose Calcisols at construction sites. *Atmospheric Environment*, 141, pp.96-105. Available at: https://doi.org/10.1016/j.atmosenv.2016.06.054.

Kinsey, J.S., Linna, K.J., Squier, W.C., Muleski, G.E. & Chatten, C.Jr. 2004. Characterization of the Fugitive Particulate Emissions from Construction Mud/Dirt Carry out. *Journal of the Air & Waste Management Association*, 54(11), pp.1394-1404. Available at: https://doi.org/10.1080/10473289.2004.10471007.

Tian, G., Qiao, Z. & Xu, X. 2014. Characteristics of particulate matter (PM_{10}) and its relationship with meteorological factors during 2001–2012 in Beijing. *Environmental Pollution,* 192, pp.266-274. Available at: https://doi.org/10.1016/j.envpol.2014.04.036.

Wei, L., Xiaohui, H., Huapeng, C., Luyao, H. & Huihua, C. 2022. Analyzed and Simulated Prediction of Emission Characteristics of Construction Dust Particles under Multiple Pollution Sources. *Computational Intelligence and Neuroscience*, 2022, art.ID:7349001. Available at: https://doi.org/10.1155/2022/7349001.

Yan, H., Ding, G., Li, H., Wang, Y., Zhang, L., Shen, Q. & Feng, K. 2019. Field Evaluation of the Dust Impacts from Construction Sites on Surrounding Areas: A City Case Study in China. *Sustainability*, 11(7), art.number:1906. Available at: https://doi.org/10.3390/su11071906.

Zhang, W., Wang, X., Liu, Z., Zhang, Y., Shao, M., Cheng, Q., Wu, D. & Ian, W. 2010. Construction Fugitive PM_{10}Emission and Its Influences on Air Quality in Guiyang. *Acta Scientiarum Naturalium Universitatis Pekinensis*, 46(2), pp.258-264 [online]. Available at: http://xbna.pku.edu.cn/EN/Y2010/V46/I2/258 [Accessed: 02 April 2023].

Zhao, Y., Yu, L., Zhang, C., Wang, Q., Jing, T. & Chen, Z. 2010. Spatial dispersion laws of particulate matter from construction work site of municipal engineering. *Ecology and Environmental Sciences*, 11, pp.2625-2628. Available at: https://doi.org/10.16258/j.cnki.1674-5906.2010.11.030.

Мониторинг и анализ качества воздуха и метеорологических параметров на строительной площадке с помощью интернета вещей

Лазар Б. Миливоевич

Университет «Унион – Никола Тесла», факультет управления строительством, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 28.23.00 Искусственный интеллект,
67.21.25 Строительная климатология, метеорология
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Строительная отрасль является одним из основных источников пылевыделения, парниковых газов и загрязнителей воздуха. Эффективная эксплуатация и управление операциями на объекте могут значительно снизить углеродный след проекта и другие воздействия на окружающую среду. При сотрудничестве научно-исследовательского *учреждения со строительными компаниями был проведен мониторинг качества воздуха на строительной площадке в режиме реального времени с использованием технологий Интернета вещей.*

Методы: Была внедрена системная платформа на основе Интернета вещей, которая интегрирует распределенную сенсорную сеть для сбора данных в режиме реального времени и демонстрации качества воздуха на строительной площадке. В ходе исследования использовались различные типы датчиков для сбора данных, относящихся к частицам NO2, PM2.5 и PM10, а также метеорологическим параметрам – скорости и направлению ветра, влажности, давлению и температуре.

Результаты: Результаты оперативных измерений дают представление о состоянии загрязнения атмосферного воздуха на строительной площадке, вызванного строительными работами, которыми можно управлять с целью снижения концентрации выхлопных газов и взвешенных частиц. В результате мониторинга строительных площадок в городе Белград выявлено, что уровень запыленности при строительстве относительно высок.

Выводы: На основании результатов исследования можно сделать вывод, что строительная деятельность оказывает значительное воздействие на качество воздуха вблизи строительной площадки. Что касается основных факторов, влияющих на выделение строительной пыли, корреляции показывают, что выделение строительной пыли не имеет значительной корреляции с метеорологическими факторами.

Ключевые слова: строительная площадка, концентрация ТЧ, корреляция, метеорология.

Мониторинг и анализа квалитета ваздуха и метеоролошких параметара на градилишту уз помоћ IoT технологија

Лазар Б. Миливојевић

Универзитет „Унион – Никола Тесла”, Факултет за градитељски менаџмент, Београд, Република Србија

ОБЛАСТ: рачунарске науке, грађевинарство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Грађевинска индустрија је један од главних произвођача прашине и гасова стаклене баште који загађују ваздух. Ефикасним функционисањем и управљањем операцијама на градилишту може се знатно смањити угљенични отисак пројекта, као и други *утицаји на животну средину. Сарадњом научноистраживачке установе и грађевинске компаније реализовано је праћење квалитета ваздуха на градилишту у реалном времену коришћењем IoT технологија.*

Методе: Имплементиран је системски оквир заснован на IoT технологијама који интегрише дистрибуирану сензорску мрежу за прикупљање података у реалном времену и демонстрирање квалитета ваздуха на градилишту. Различити типови сензора коришћени су за прикупљање података који се односе на NO2 и честице PM2,5, PM10, као и на метеоролошке параметре – брзину и смер ветра, влажност, притисак и температуру.

Резултати: Резултати мерења у реалном времену приказују слику стања загађености ваздуха на градилишту и повезаност са грађевинским активностима којима се може управљати како би се смањила концентрација загађујућих гасова и суспендованих честица. Праћењем градилишта у Београду утврђено је да је ниво прашине услед грађевинских активности релативно висок.

Закључак: Грађевинска активност имала је значајан утицај на квалитет ваздуха у околини грађевинског подручја. Што се тиче главних фактора који утичу на емисију грађевинске прашине, корелације показују да емисија грађевинске прашине није у значајној корелацији са метеоролошким факторима.

Кључне речи: градилиште, концентрација PM, корелација, метеорологија.

Paper received on / Дата получения работы / Датум пријема чланка: 03.04.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 13.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 15.06.2023.

Contribution to the research of oscillatory loads of sprung and unsprung masses in order to create conditions for laboratory tests of heavy motor vehicles

Miroslav D. Demić[a], *Aleksandar* S. Đurić[b], *Aleksandar* R. Grkić[c], *Momir* M. Drakulić[d], *Slavko* Muždeka[e]

[a] Engineering Science Academy of Serbia,
Belgrade, Republic of Serbia,
e-mail: demic@kg.ac.rs,
ORCID iD: https://orcid.org/0000-0003-2168-1370

[b] University of Defence in Belgrade, Military Academy,
Department of Military Mechanical Engineering,
Belgrade, Republic of Serbia,
e-mail: aleksandar_djrc@yahoo.com, **corresponding author**,
ORCID iD: https://orcid.org/0000-0002-2165-528X

[c] Auto Moto Association of Serbia, Center for Motor Vehicles,
Belgrade, Republic of Serbia,
e-mail: aleksandargrkic@gmail.com,
ORCID iD: https://orcid.org/0000-0002-7890-1787

[d] University of Defence in Belgrade, Military Academy,
Department of Military Mechanical Engineering,
Belgrade, Republic of Serbia,
e-mail: drakulic.momir@gmail.com,
ORCID iD: https://orcid.org/0000-0002-8367-7281

[e] University of Defence in Belgrade, Military Academy,
Department of Military Mechanical Engineering,
Belgrade, Republic of Serbia,
ORCID iD: https://orcid.org/0000-0002-6189-9473

DOI: 10.5937/vojtehg71-43221; https://doi.org/10.5937/vojtehg71-43221

FIELD: mechanical engineering
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Motor vehicles are complex dynamic systems due to spatial displacements, changes in the characteristics of components during their lifetime, a large number of influences and disturbances, the appearance of backlash, friction, hysteresis, etc. The aforementioned dynamic phenomena, especially vibrations, cause driver and passenger fatigue, reduce the lifetime of the vehicle and its systems, etc.

Methods: In general, the movement of vehicles is carried out on uneven roads and curvilinear paths in the road. Not only do oscillatory movements cause material fatigue of vehicle parts, but they also have a negative effect *on people's health. That is why special attention must be paid to the coordination of the mutual movement of the subsystems, and in particular, the vehicle suspension system, even at the stage of the motor vehicle design. For these purposes, theoretical, experimental or combined methods can be used. Therefore, it is very useful to have the experimental results of the oscillations of the vehicle subsystem in operating conditions, so the aim of this work was to use the movement of the 4x4 drive FAP 1118 vehicle in operating conditions (due to higher speeds - in road conditions) to define the conditions for testing oscillatory loads in laboratory conditions.*

Results:This is made possible by registering and identifying statistical parameters of registered quantities.

Conclusion: Based on the measured data, the research can be programmed on shakers in laboratory conditions, and, at the same time, the size to be reproduced can be chosen as well.

Key words: motor vehicle, sprung and unsprung masses, oscillatory loads, laboratory tests.

Introduction

Motor vehicles are complex dynamic systems due to the appearance of spatial vibrations in movement, changes in the characteristics of components during their lifetime, a large number of influences and disturbances, the appearance of clearances, friction, hysteresis, etc. (Demić, 1997, 2006, 2008; Demić & Diligenski, 2003; Abe, 2009; Ellis, 1969; Milliken & Milliken, 1994; Genta, 1997; Gillespie, 1992; Rajamani, 2006). The aforementioned dynamic phenomena, especially vibrations, cause driver and passenger fatigue, reduce the lifetime of the vehicle and its systems, etc.

In general, the movement of vehicles is carried out on uneven roads (terrain) and curvilinear paths in the road (terrain). Oscillatory movements cause load on vehicle parts, but also have a negative effect on human health (Demić, 2008; Hachaturov, 1976; Fiala, 2006; Simić, 1980). That is why special attention must be paid to the coordination of the mutual movement of the vehicle subsystems, and in particular, the suspension system, even at the stage of designing a motor vehicle (Demić, 1997). For these purposes, theoretical, experimental or combined methods can be used, and it is very useful to have experimental results of vehicle subsystem oscillations in operational conditions.

The road (terrain) can be identified based on its spatial geometry (macrorelief) and microbumps (microrelief) (Jovanović & Đurić, 2009; Demić et al, 2022).

The movements of the vehicle subsystem are conditioned, first of all, by the shape and size of bumps as an external factor and oscillatory-inertial characteristics, the torque of the engine and the vehicle velocity as the phenomena related to the vehicle itself. Based on this, it can be concluded that careful research and definition of the characteristics of microbumps of roads on which vehicles drive, both from the aspect of the characteristics of periodicity and from the aspect of energy levels, elaboration and automation of the process of measuring bumps and the mathematical apparatus for processing the obtained data, contribute to reliability, optimality and safety of the construction of the vehicle itself. As the description of road parameters and their identification are given in detail in (Demić, 1997, 2008; Demić et al, 2022; Abe, 2009; Jovanović & Đurić, 2009; Genta, 1997; Gillespie, 1992; Đurić, 2009; ISO, 1995), there will be no more talk about it in this paper.

As it is known (Cox & Reid, 2000), in laboratory conditions, signals recorded during exploitation can be reproduced on pulse generators. Therefore, the aim of this work was to establish the oscillatory movements of sprung and unsprung masses of the vehicle in operational conditions (when driving in road conditions), FAP 1118 vehicle, in order to create the conditions for laboratory tests.

Oscilatory loads measurement for sprung and unsprung vehicle masses

In order to determine oscilatory loads of sprung and unsprung masses of a vehicle, we need to measure specific parameters in real conditions of vehicle exploitation. Experiment design is a complex issue (Cox & Reid, 2000). In this specific case, the subject of the research was a FAP 1118 motor vehicle with 4x4 drive and a load capacity of 4t. The maximum mass of the test vehicle is 11,000 kg, and during the test the vehicle was partially loaded (total mass 7,800 kg - the static load of the front axle was 4,200, and at the rear axle it was 2,850 daN). The measuring chain for measuring the dynamic parameters of the vehicle consisted of the following elements:

- Kistler Correvit S-350 sensors, manufactured by Kistler group, Switzerland, for direct slip-free measurement of longitudinal and transverse vehicle dynamic studying and experimenting (taking into account overall interactions of a complex system or a subsystem within a complex system),

- HBM Quantum MX 840B, made by HBK from Germany, a universal measuring acquisition system,

- B-12 acceleration sensor, made by HBK, Germany, located in the center of gravity of the rear truck bridge, and
- SST 810 dynamic inclinometer, manufactured by Vigor Technology, Greece, placed in the center of gravity of the vehicle.

The measurement was done in Catman software, developed by HBK, Germany.

Based on previous experience and the measurements made at the Military Academy during tests for regular classes and research studies for some doctoral dissertations (Grkić, 2015; Muždeka, 2008), it was considered expedient to test the vehicle while driving in real operational conditions, on an asphalt regional road near Belgrade (maximum driving speed, 56.2 km/h - maximum vehicle speed 80 km/h). During the experiment, the weather was nice and the road was dry. The length of time records was 260 s (13000 points and a discretization step of 0.02 s).

The scheme of measuring points is given in Fig. 1 and for further analysis, Figs. 2 - 4 partially show changes in the vehicle speed over time and the oscillatory movements of the drive axles.

Analyzing all the registered values, partially shown in Figs. 2-4, one can notice that the registered parameters of the vehicle movement depend on time. At the same time, they belong to the group of random processes (Bendat & Piersol, 2000). There is a whole range of methods for processing such signals (Bendat & Piersol, 2000), and we will use some of them in this paper.

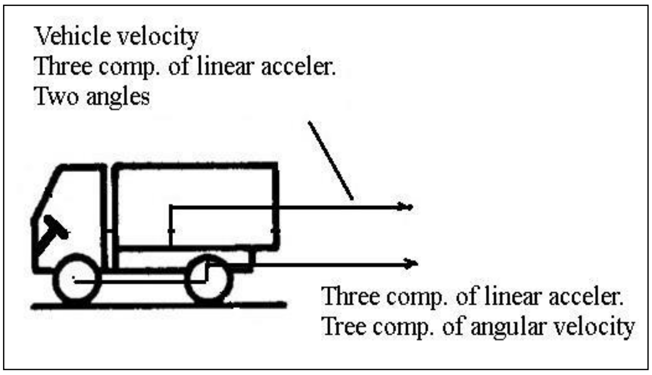


Figure 1 – Scheme of the measurement points on the FAP 1118 during testing
Рис. 1 – Схема точек измерения на ФАП 1118 при испытаниях
Слика 1 – Шема мерних тачака на возилу ФАП 1118 током испитивања

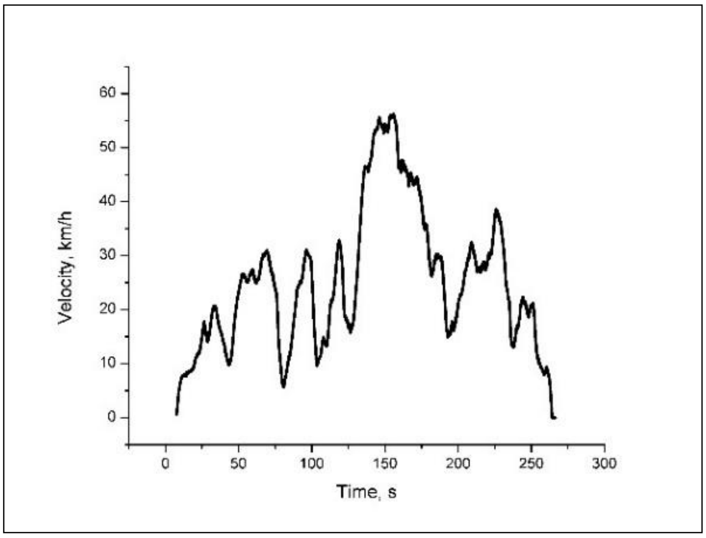


Figure 2 – Vehicle velocity change while driving
Рис. 2 – Изменение скорости автомобиля во время движения
Слика 2 – Промена брзине возила током вожње

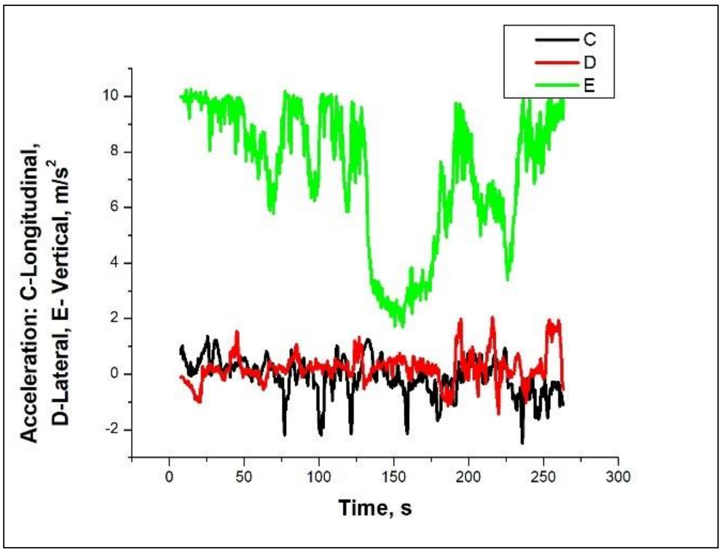


Figure 3 – Longitudinal, lateral and vertical acceleration of the front unsprung mass
Рис. 3 – Продольное, поперечное и вертикальное ускорение передней неподрессоренной массы
Слика 3 – Подужно, бочно и вертикално убрзање предње неослоњене масе возила

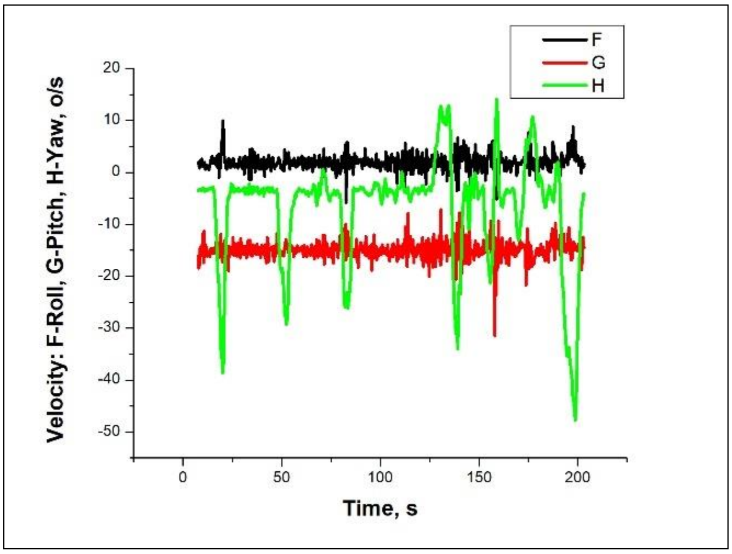


Figure 4 – Roll, pitch and yaw velocity of the rear unsprung mass of the vehicle
Рис. 4 – Скорость крена, тангажа и рыскания задней неподрессоренной массы транспортного средства
Слика 4 – Угаоне брзине ваљања, галопирања и вијугања задње неослоњене масе возила

Data processing

There are several methodes for data processing in the literature. In (Bendat & Piersol, 2000), it is suggested that the identification of random processes is performed in the time, frequency and amplitude domains. This approach is also adopted in this work.

Identification of data in the time domain

Having in mind the random character of all registered quantities, it was considered expedient to calculate the parameters in the time domain that will later be used for analysis (especially during amplitude identification, and the calculations were performed using Statisdem software developed in Pascal). This primarily refers to the threshold, the mean value and the standard deviation of all registered quantities. For the sake of illustration, Tables 1, 2 and 3 show the calculated values.

In order to determine the character of the registered values (stationarity), with use of Analisigdem software developed in Pascal, the autocorrelation functions were calculated and partially shown in Figs. 5, 6 and 7 and shown in Tables 1, 2 and 3.

Table 1 – Characteristic values of the registered sizes of the sprung mass
Таблица 1 – Характерные значения зарегистрированных размеров подрессоренной массы транспортного средства
Табела 1 – Карактеристичне вредности регистрованих величина ослоњене масе возила

Measured parameters	Min. value	Max. value	Mean value	Stand. Dev.
Vehicle velocity, km/h	0.612	56.232	25.428	12.925
Longitudinal acceleration, m/s2	-55.880	29.760	0.311	3.672
Lateral acceleration, m/s^2	-44.800	28.120	0.186	3.967
Vertical acceleration, m/s^2	-17.510	37.730	9.798	3.454
Roll, o	-14.965	15.518	1.550	4.942
Pitch, o	-9.995	15.375	2.283	3.728

Table 2 – Characteristic values of the registered values of the front unsprung mass
Таблица 2 – Характерные значения зарегистрированных значений передней неподрессоренной массы транспортного средства
Табела 2 – Карактеристичне вредности регистрованих величина предње неослоњене масе возила

Measured parameters	Min. value	Max. value	Mean value	Stand. Dev.
Vehicle velocity, km/h	-3.272	1.648	-0.087	0.705
Longitudinal acceleration, m/s2	-5.457	5.615	0.223	0.758
Lateral acceleration, m/s^2	-4.249	18.717	7.248	2.701
Vertical acceleration, m/s^2	-4.809	54.078	2.310	3.451
Roll, o	-16.685	18.639	0.998	2.099
Pitch, o	-38.175	20.254	3.185	8.684

Table 3 – Characteristic values of the registered sizes of the rear unsprung mass
Таблица 3 – Характерные значения зарегистрированных размеров задней неподрессоренной массы транспортного средства
Табела 3 – Карактеристичне вредности регистрованих величина задње неослоњене масе возила

Measured parameters	Min. value	Max. value	Mean value	Stand. Dev.
Vehicle velocity, km/h	-8.856	5.030	0.278	0.996
Longitudinal acceleration, m/s2	-4.741	7.515	0.256	0.913
Lateral acceleration, m/s^2	-10.120	31.985	9.659	2.037
Vertical acceleration, m/s^2	-45.1835	53.461	1.940	5.534
Roll, o	-47.081	24.568	14.836	3.447
Pitch, o	-48.444	16.297	6.603	10.191

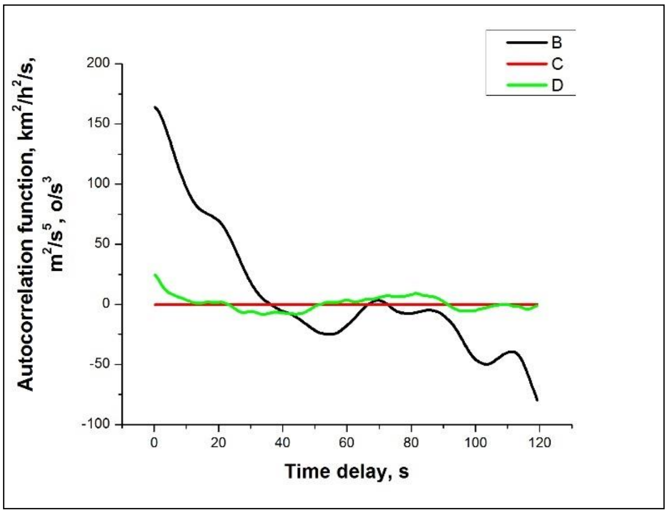


Figure 5 – Autocorrelation function of the velocity (B), the vertical acceleration (C) and the roll angle (D) of the sprung mass
Рис. 5 – Автокорреляционная функция скорости (B), вертикального ускорения (C) и угла крена (D) подрессоренной массы
Слика 5 – Аутокорелациона функција брзине (B), вертикалног убрзања (C) и угла ваљања (D) ослоњене масе

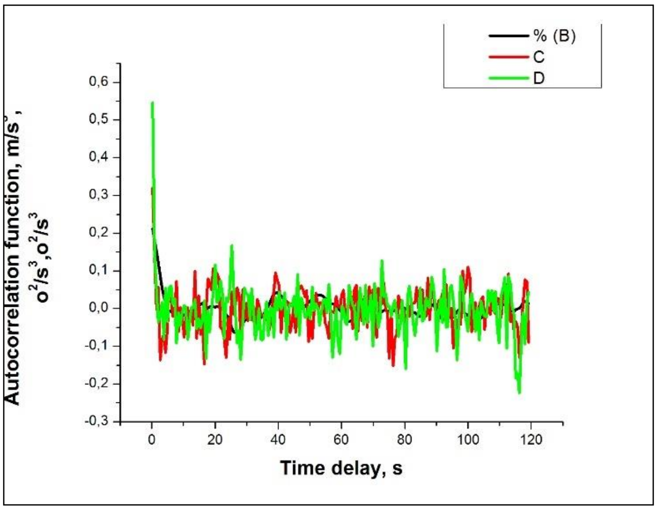


Figure 6 – Autocorrelation function of the lateral acceleration (B), the roll angular velocity (C) and the pitch (D) of the front unsprung mass
Рис. 6 – Автокорреляционная функция бокового ускорения (B), угловой скорости крена (C) и тангажа (D) передней неподрессоренной массы
Слика 6 – Аутокорелациона функција бочног убрзања (B), угаоне брзине ваљања (C) и угаоне брзине галопирања (D) предње неослоњене масе

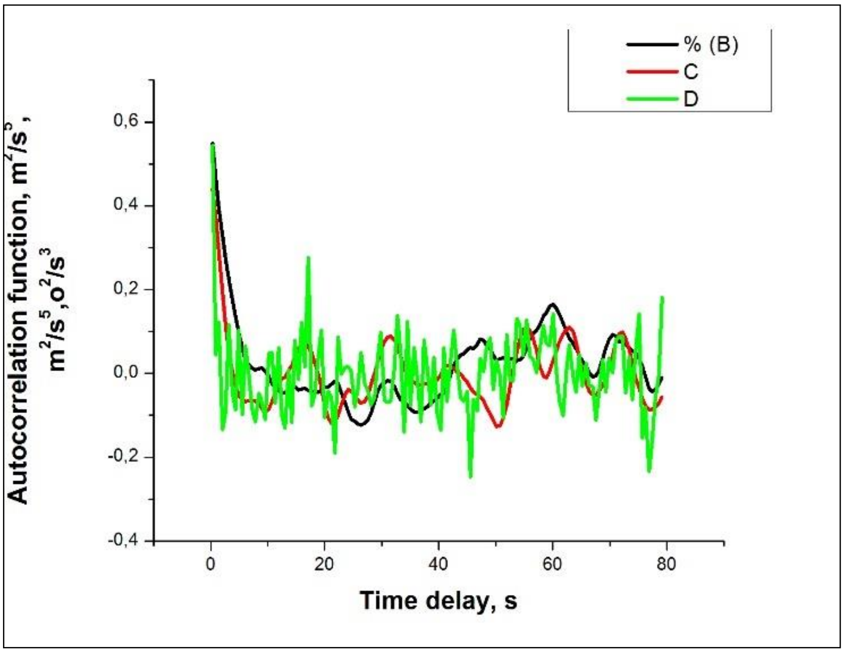


Figure 7 – Autocorrelation function of the longitudinal acceleration (B), the lateral acceleration (C) and the pitch (D) of the rear unsprung mass
Рис. 7 – Автокорреляционная функция продольного ускорения (B), поперечного ускорения (C) и шага (D) задней неподрессоренной массы
Слика 7 – Аутокорелациона функција бочног убрзања (B), угаоне брзине ваљања (C) и угаоне брзине галопирања (D) предње неослоњене масе

Data identification in the frequency domain

Frequency analysis was performed using Analsigdem software (Demić et al, 2001) with 8192 points and a discretization step of 0.02 s, which enabled a reliable analysis in the region of 0.061 to 25 Hz (Bendat & Piersol, 2000).

The analysis of random and bias errors, for the number of data used, showed that a sufficient number of averaging is 100 for one signal and 138 for two signals, which achieves a minimum reliable frequency of 0.049 Hz (this is acceptable in this experiment because it is lower than the one that is obtained based on the length of the signal (Bendat & Piersol, 2000). Bearing in mind that the phases of the calculated spectra do not allow the analysis of the energy carried by the signal, it was considered expedient to observe only the magnitudes of the calculated spectra, which are partially shown in Figs. 8, 9 and 10.

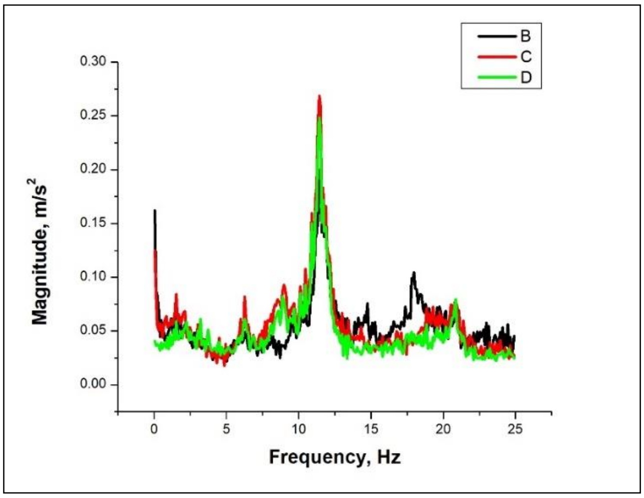


Figure 8 – Spectra magnitude of the sprung mass: Longitudinal (B), lateral (C) and vertical acceleration (D)
Рис. 8 – Амплитудный спектр подрессоренной массы: продольное (B), поперечное (C) и вертикальное ускорение (D)
Слика 8 – Магнитуда спектра ослоњене масе: подужно (B), бочно (C) и вертикално убрзање (D)

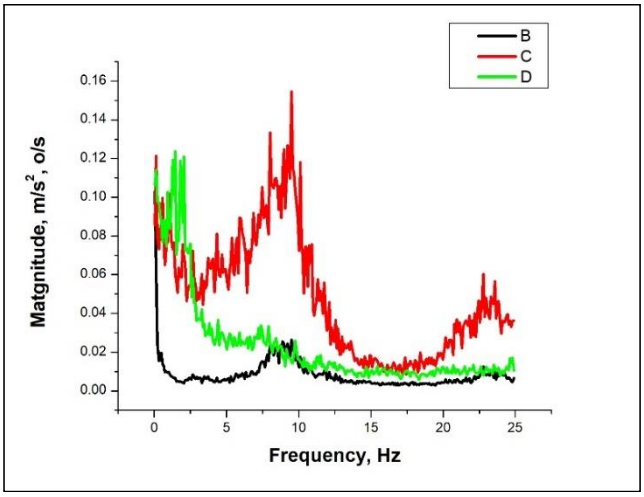


Figure 9 – Spectra magnitude of the front unsprung mass: Lateral Acceleration (B), Roll (C) and pitch (D)
Рис. 9 – Амплитудный спектр передней неподрессоренной массы: боковое ускорение (B), крен (C) и тангаж (D)
Слика 9 – Магнитуда спектра предње неослоњене масе: бочно убрзање (B), угаона брзина ваљања (C) и угаона брзина галопирања (D)

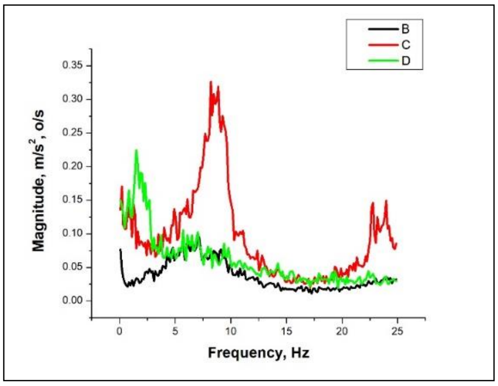


Figure 10 – Magnitude spectrum of the rear unsprung mass: vertical acceleration (B), roll (C) and pitch (D)
Рис. 10 – Амплитудный спектр задней неподрессоренной массы: вертикальное ускорение (B), крен (C) и тангаж (D)
Слика 10 – Магнитуда спектра задње неослоњене масе: вертикално убрзање (B), угаона брзина ваљања (C) и угаона брзина галопирања (D)

Identification of data in the amplitude domain

After all data analysis previously mentioned and given in (Bendat & Piersol, 2000; Demić et al, 2001; Vukadinović, 1973; O`Connor & Kleyner, 2012), more amplitude analyses were carried out for all registered values. More precisely, the probability of occurrence of the observed quantity was calculated by levels (Probability density-histogram, %), with the use of a specially developed program in Pascal, Statistdem. The calculated values are, for the sake of illustration, partially shown in Figs. 11-17.

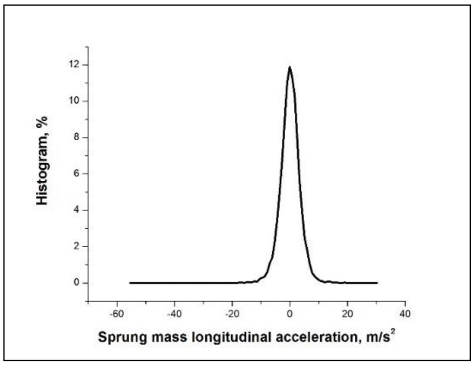


Figure 11 – Density of the distribution of the longitudinal accelerations of the vehicle sprung mass
Рис. 11 – Плотность распределения продольных ускорений подрессоренной массы транспортного средства
Слика 11 – Густина расподеле подужних убрзања ослоњене масе возила

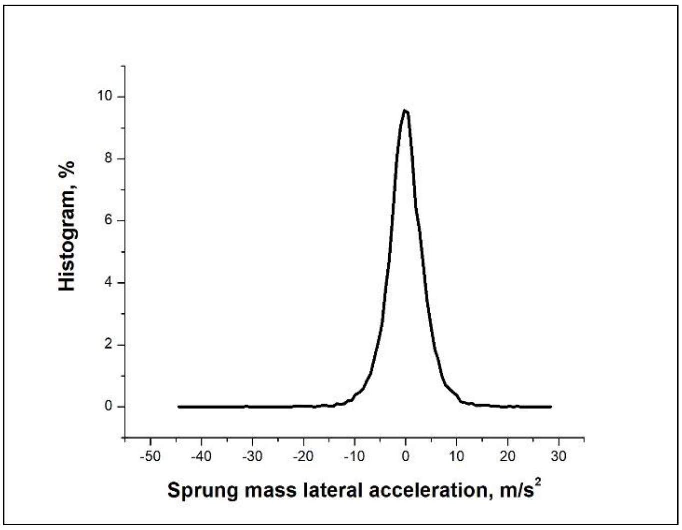


Figure 12 – Density of the distribution of the lateral accelerations of the sprung mass of the vehicle
Рис. 12 – Плотность распределения боковых ускорений подрессоренной массы транспортного средства
Слика 12 – Густина расподеле бочних убрзања ослоњене масе возила

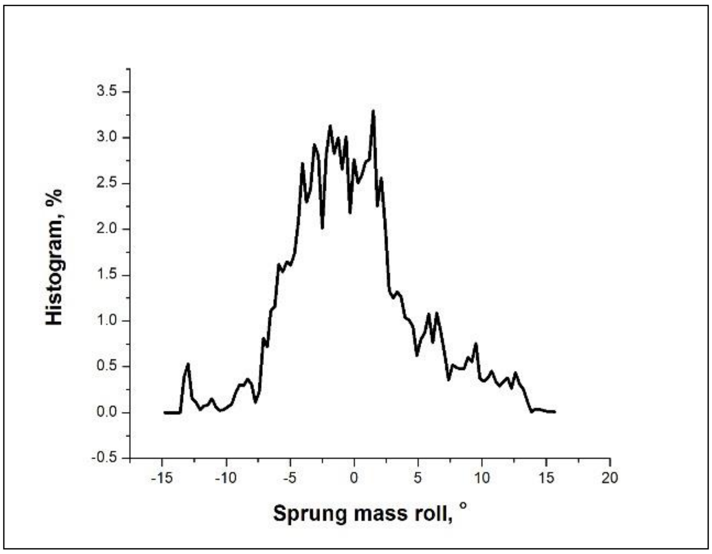


Figure 13 – Density of the roll angle distribution of the sprung mass of the vehicle
Рис. 13 – Плотность распределения подрессоренной массы транспортного средства по углу крена
Слика 13 – Густина расподеле угла ваљања ослоњене масе возила

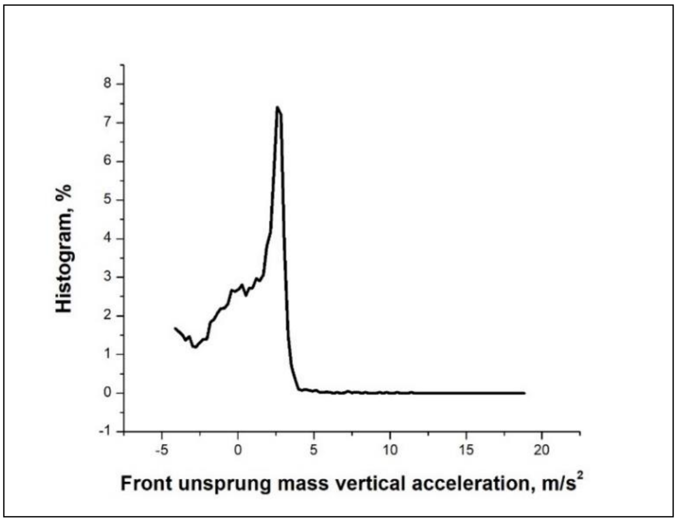


Figure 14 – Density of the distribution of the vertical accelerations of the front unsprung mass of the vehicle
Рис. 14 – Плотность распределения вертикальных ускорений передней неподрессоренной массы транспортного средства
Слика 14 – Густина расподеле вертикалних убрзања предње неослоњене масе возила

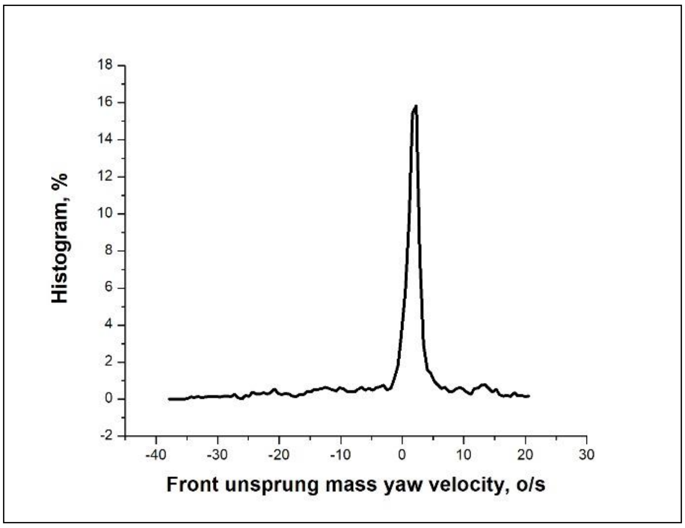


Figure 15 – Density of the yaw distribution of the front unsprung mass of the vehicle
Рис. 15 – Плотность распределения угловых скоростей рыскания передней неподрессоренной массы транспортного средства
Слика 15 – Густина расподеле угаоне брзине вијугања предње неослоњене масе возила

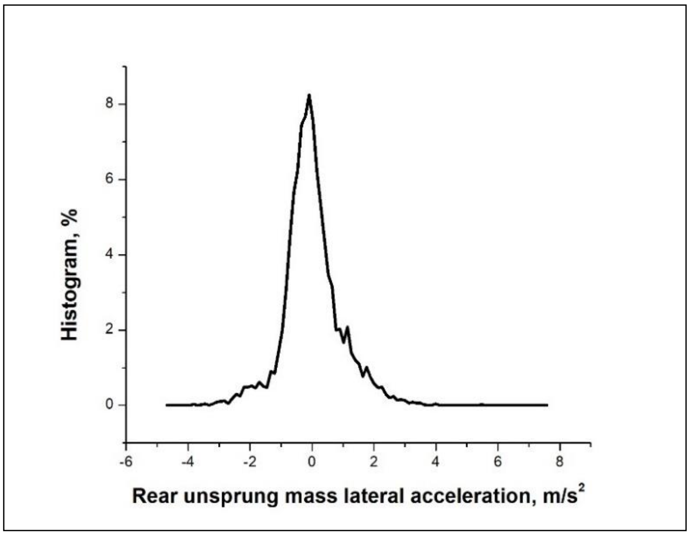


Figure 16 – Density of the distribution of the lateral accelerations of the rear unsprung mass of the vehicle
Рис. 16 – Плотность распределения боковых ускорений задней неподрессоренной массы транспортного средства
Слика 16 – Густина расподеле бочних убрзања задње неослоњене масе возила

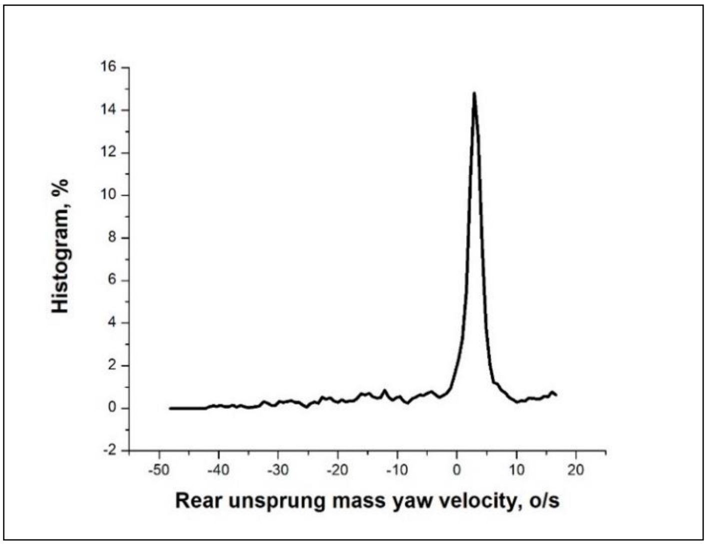


Figure 17 – Density of the yaw distribution of the rear sprung mass of the vehicle
Рис. 17 – Плотность распределения угловых скоростей рыскания задней неподрессоренной массы транспортного средства
Слика 17 – Густина расподеле угаоне брзине вијугања задње неослоњене масе возила

Discussion of the analyzed data

Based on Tables 1-3, it is obvious that there are differences in the levels of the registered values for both unsprung and sprung masses, which indicates the necessity of performing more detailed analyses.

Analyzing all the calculated values of the autocorrelation functions, partially for the sake of illustration, shown in Figs. 5-7, it was determined that they decrease with increasing time delay, or slightly oscillate around the zero value (the exception is the case of velocity). Bearing in mind (Bendat & Piersol, 2000), it can be concluded that all the values, except the vehicle velocity, can be considered as stationary and the theory of stationary random processes can be used for their identification.

The analysis of all calculated spectrum modules, partially shown in Figs. 8-10, showed that the largest amplitudes are not unique: they depend on the measuring place (sprung and unsprung mass), as well as on the registered value.

In the spectrograms, there are usually three areas where extreme values are expressed, approximately in 1-2, 9-11 and 17-24 Hz. Based on (Simić, 1980), it can be argued that the resonances in the 1-2 Hz range originate from the sprung mass, 9-11 from the drive group, and in the range of 17-24 Hz from the unsprung masses. This statement is important for programming the test of the observed vehicle in laboratory conditions. It should be noted that, in practice, the vehicle suspension system is usually designed according to the resonance of the vertical vibrations of the sprung and unsprung masses of the vehicle (Mitschke, 1972), which will not be discussed here.

It is usual to start the initial statistical analysis by applying the so-called Null hypotheses (Vukadinović, 1973; O`Connor & Kleyner, 2012). In this particular case, the normality of the distribution of the mean value of the measured quantities was tested, in relation to the basic set (with an infinite number of members), with a significance level of 5%.

Namely, for the adopted significance level of 0.05, the value gr was calculated according to the expression (Vukadinović, 1973; O`Connor & Kleyner, 2012):

$$gr = \frac{1.96\sigma}{\sqrt{n}} \tag{1}$$

where

σ - standard deviation, and

n - number of samples in the set.

The hypothesis is confirmed if the absolute value of the mean value of the registered quantity is smaller than the size gr (Vukadinović, 1973; O`Connor & Kleyner, 2012).

More precisely, using the Statisdem program, an analysis of the correctness of the adopted Null hypothesis (in the specific case for the mean value of 0) was performed for all measured quantities (Tables 4, 5 and 6).

Table 4 – Normality test-Null hypothesis-Dependent mass: significance level of 0.05
Таблица 4 – Тест на нормальность - масса, зависящая от нулевой гипотезы-подрессоренная масса: уровень значимости 0,05
Табела 4 – Тест нормалности – нулта хипотеза – ослоњена маса: ниво значајности 0,05

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s^2	Roll angle, ^{o}	Pitch angle, ^{o}	Veh. velocity, km/h
Abs. val. of middle val. of sample	0.311	0.186	9.798	1.550	2.283	25.428
Value gr	0.065	0.071	0.062	0.089	0.061	0.228

Table 5 – Normality test-Null hypothesis-Front unsprung mass: significance level of 0.05
Таблица 5 – Тест на нормальность - Нулевая гипотеза - Передняя неподрессоренная масса: уровень значимости 0,05
Табела 5 – Тест нормалности – нулта хипотеза – предња неослоњена маса: ниво значајности 0,05

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll, o/s	Pitch, o/s	Yaw, o/s
Abs. val. of middle val. of sample	0.0879	0.223	7.248	2.310	0.998	3.185
Value gr	0.012	0.012	0.048	0.062	0.037	0.1026

Table 6 – Normality test-Null hypothesis-Rear unsprung mass: significance level of 0.05
Таблица 6 – Тест на нормальность - Нулевая гипотеза - Задняя неподрессоренная масса: уровень значимости 0,05
Табела 6 – Тест нормалности – нулта хипотеза – задња неослоњена маса: ниво значајности 0,05

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll, o/s	Pitch, o/s	Yaw, o/s
Abs. val. of middle val. of sample	0.211	0.194	7.337	1.473	0.713	1.641
Value gr	0.021	0.020	0.047	0.127	0.079	0.183

By analyzing the data from Tables 4, 5 and 6, it can be concluded that the Null hypothesis was not satisfied in any case, for the significance level of 0.05 (Vukadinović, 1973). Therefore, alternative hypotheses must be used, which will be discussed later.

In statistics, there is often a task to define intervals that satisfy the probability of 0.95 (the significance level of 0.05). The calculations were performed using the Statisdem program, and the values are shown in Tables 7, 8 and 9.

Table 7 – Value limits of the measured values of the sprung mass for the significance level of 0.05
Таблица 7 – Предельные значения измеренных величин подрессоренной массы по уровню значимости 0,05
Табела 7 – Граничне вредности измерених величина ослоњене масе за ниво значајности 0,05

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s^2	Roll angle, °	Pitch angle, °	Veh. velocity, km/h
Min.	-7.43	-7.97	-6.90	-8.19	-6.92	0.61
Max.	6.40	8.23	7.04	12.13	8.19	28.14

Table 8 – Limits of the values of the measured sizes of the front unsprung mass for the significance level of 0.05
Таблица 8 – Предельные значения измеренных величин передней неподрессоренной массы по уровню значимости 0,05
Табела 8 – Граничне вредности измерених величина предње неослоњене масе за ниво значајности 0,05

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll, o/s	Pitch, o/s	Yaw, o/s
Min.	-1.68	-1.43	-4.24	-6.81	-4.19	-17.67
Max.	1.20	1.58	3.17	6.60	4.72	15.98

Table 9 – Threshold values of the measured sizes of the rear sprung mass for the significance level of 0.05
Таблица 9 – Предельные значения измеренных величин задней подрессоренной массы по уровню значимости 0,05
Табела 9 – Граниче вредности измерених величина задње неослоњене масе за ниво значајности 0,05

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s^2	Roll, o/s	Pitch, o/s	Yaw, o/s
Min.	-2.12	-2.01	-4.16	-10.3	-7.27	-22.8
Max.	1.66	2.19	4.33	11.61	7.92	14.03

Demić, M. et al, Contribution to the research of oscillatory loads of sprung and unsprung masses in order to create conditions for laboratory tests of heavy motor vehicles, pp.647-677

The data from Tables 7, 8 and 9 can be useful when defining the test conditions of an observed test vehicle in laboratory conditions.

A very important step in amplitude identification is hypothesis testing. There are several tests for that purpose, but the so-called The Romanovsky test was used as a simple test and as a superstructure for the test. χ2 which will be briefly explained. The χ2 test (Vukadinović, 1973) is defined as:

$$\chi^2 = \sum_{1}^{N} \frac{\left(f_i - f_{ti} \right)^2}{f_{ti}} \tag{2}$$

where
fi - frequency of the i-th class,
fti - theoretical frequency of the i-th class, and
N - number of classes.

In (Vukadinović, 1973), a simple Romanovski criterion is given, which is defined by the expression:

$$R = \frac{\left| \chi^2 - k \right|}{\sqrt{2k}} \tag{3}$$

where

$$K = N - l - 1 \tag{4}$$

In expression (4):

- N - number of additions in (1) and
- l - the number of unknown parameters in the assumed probability distribution.

The hypothesis is accepted if R<3, and rejected if R>3.

Bearing in mind that the mean values of the registered values are not always positive, it was considered expedient to perform hypothesis tests with Gaussian and Laplace distributions (Vukadinović, 1973; O`Connor & Kleyner, 2012). Previously, based on experimental and theoretical distribution functions, using the method of minimizing the square of the difference, the parameters of the Laplace distribution were identified (this procedure is based on the application of the Hooke-Jeves method and is covered in detail in (Demić, 1997), so it will not be discussed further). Using Statistdem software, the values for R were calculated and given in Tables 10, 11 and 12.

Table 10 – Values of the Romanovsky criterion for the sprung mass
Таблица 10 – Значения критерия Романовского для подрессоренной массы
Табела 10 – Вредности критеријума Романовског за ослоњену масу

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll angle, º	Pitch angle, º	Veh. velocity, km/h
Gaussian distribution	2.0867 E+41	5.2975 E+12	1.5914 E+6	6.846	6.792	6.841
Laplace distribution	6.890	6.941	6.922	6.904	6.859	6.920

Table 11 – Values of the Romanovsky criterion for the front unsprung mass
Таблица 11 – Значения критерия Романовского для передней неподрессоренной массы
Табела 11 – Вредности критеријума Романовског за предњу неослоњену масу

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll, o/s	Pitch, o/s	Yaw, o/s
Gaussian distribution	5.668	2.160E +02	3.207	2.2769 E+35	7.970E+0 4	6.838
Laplace distribution	6.836	6.680	6.813	1.967E +03	6.861	6.514

Table 12 – Values of the Romanovsky criterion for the rear unsprung mass
Таблица 12 – Значения критерия Романовского для задней неподрессоренной массы
Табела 12 – Вредности критеријума Романовског за задњу неослоњену масу

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll, o/s	Pitch, o/s	Yaw, o/s
Gaussian distribution	9.016E +08	4.404E +03	7.708E +12	1.059E +10	2.324E+1 9	6.807
Laplace distribution	6.734	6.741	6.889	6.935	6.929	4.862

By analyzing the data from Tables 10-12, it can be determined that not a single registered value is subject to the Gaussian and two-parameter Laplace distribution. Moreover, in most cases, there is a better match with the Laplace distribution. Bearing this in mind, it was considered expedient to perform an additional check using the Kolmogorov-Smirnov test (Vukadinović, 1973; O`Connor & Kleyner, 2012), the idea of which will be briefly explained.

First, the difference between theoretical and experimental cumulative probability is formed, and its maximum absolute value is calculated, i.e:

$$D_n = \max\left|P_t(x) - P_e(x)\right|, x \in (-\infty, +\infty) \qquad (5)$$

where
P_t and P_e – theoretical and experimental cumulative distributions, respectively, and
x – the variable whose probability is being analyzed.

The criterion for testing the hypothesis is given by the expression:

$$LimP(D_n\sqrt{n} < \lambda) = Q(\lambda) = \sum_{-\infty}^{\infty}(-1)^k e^{-2k^2\lambda^2} \qquad (6)$$

where
λ – evaluation parameter,
k – index, and
Q – probability function.

The procedure consists of calculating the size $D_n\sqrt{n}$ and then for the adopted significance level, e.g. α=0.05, it is calculated by the desired probability, i.e.:

$$Q_{95} = 1 - \alpha = 1 - 0.05 = 0.95 \qquad (7)$$

Based on expression (7), from the series of the values calculated for Q as a function of λ (calculated using Statistdem software, and there are also Tables in (Vukadinovic, 1973; O`Connor & Kleyner, 2012), the quantity corresponding to the probability of 0.95 is determined, i.e. $\lambda_{0.95}$. In this specific case, for the probability of 0.95 (the significance level of 0.05), $\lambda_{0.95}$=1.363. Now comparing the sizes $D_n\sqrt{n}$ with $\lambda_{0.95}$. If $D_n\sqrt{n}$ is bigger than 1.363, then the hypothesis is rejected.

For further analysis, a value was calculated for all registered sizes $D_n\sqrt{n}$ and shown in Tables 13, 14 and 15.

Bearing in mind the data from Tables 13, 14 and 15, as well as the Kolmogorov-Smirnov criterion, it can be claimed that not a single registered quantity is subject to the Gaussian and Laplace distribution (as well as in the case of applying the Romanovsky criterion). It was considered expedient to show some of the approximate results in Figs. 18-23 for the sake of illustration.

Table 13 – $D_n\sqrt{n}$ max values for the Kolmogorov-Smirnov test for the sprung mass
Таблица 13 – Значения $D_n\sqrt{n}$ макс. по тесту Колмогорова-Смирнова для подрессоренной массы
Табела 13 – Вредности $D_n\sqrt{n}$ макс. за Колмогоров-Смирнов тест за ослоњену масу

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll angle, º	Pitch angle, º	Veh. velocity, km/h
Gaussian distribution	70.075	119.973	1115.042	135.715	423.314	665.677
Laplace distribution	491.399	196.510	247.475	542.993	506.152	254.032

Table 14 – $D_n\sqrt{n}$ max values for the Kolmogorov-Smirnov test for the front unsprung mass
Таблица 14 – $D_n\sqrt{n}$ макс. значения по тесту Колмогорова-Смирнова для передней неподрессоренной массы
Табела 14 – Вредности $D_n\sqrt{n}$ макс. ***Error! Bookmark not defined.****за Колмогоров-Смирнов тест за предњу неослоњену масу*

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll, o/s	Pitch, o/s	Yaw, o/s
Gaussian distribution	113.691	255.286	1034.683	577.797	378.897	491.697
Laplace distribution	1084.639	724.010	652.474	404.340	268.824	139.788

Table 15 – $D_n\sqrt{n}$ max values for the Kolmogorov-Smirnov test for the rear unsprung mass
Таблица 15 – $D_n\sqrt{n}$ макс. по тесту Колмогорова-Смирнова для задней неподрессоренной массы
Табела 15 – $D_n\sqrt{n}$ макс. за Колмогоров-Смирнов тест за задњу неослоњену масу

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll, o/s	Pitch, o/s	Yaw, o/s
Gaussian distribution	139.528	208.358	958.797	225.617	941.660	475.060
Laplace distribution	484.170	625.340	246.347	225.691	279.450	152.903

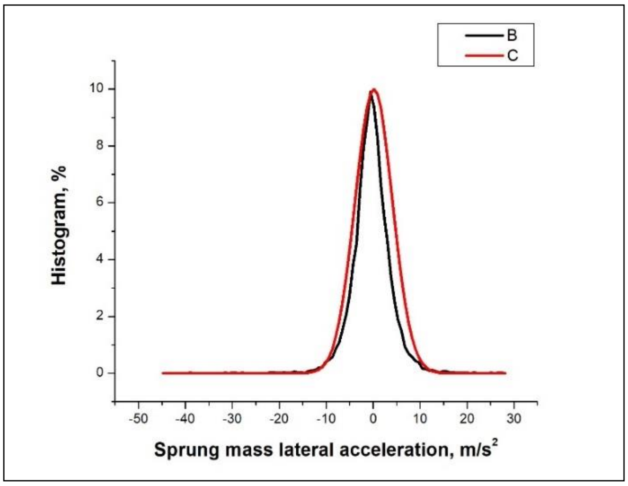


Figure 18 – Gaussian approximation of the lateral accelerations of the sprung mass (B-Experiment, C-Theory)
Рис. 18 – Гауссова аппроксимация боковых ускорений подрессоренной массы (В-эксперимент, С-теория)
Слика 18 – Гаусова апроксимација бочних убрзања ослоњене масе (В –експеримент, С – теорија)

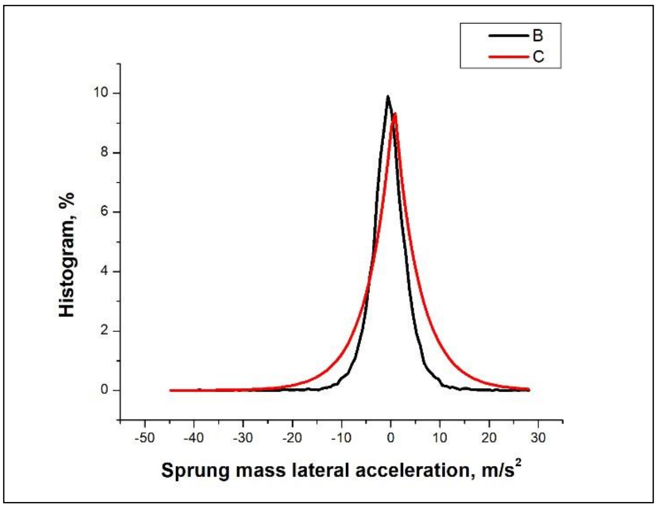


Figure 19 – Laplace approximation of the lateral accelerations of the sprung mass (B-Experiment, C-Theory)
Рис. 19 – Аппроксимация Лапласа поперечных ускорений подрессоренной массы (В-эксперимент, С-теория)
Слика 19 – Лапласова апроксимација бочних убрзања ослоњене масе (В –експеримент, С –теорија)

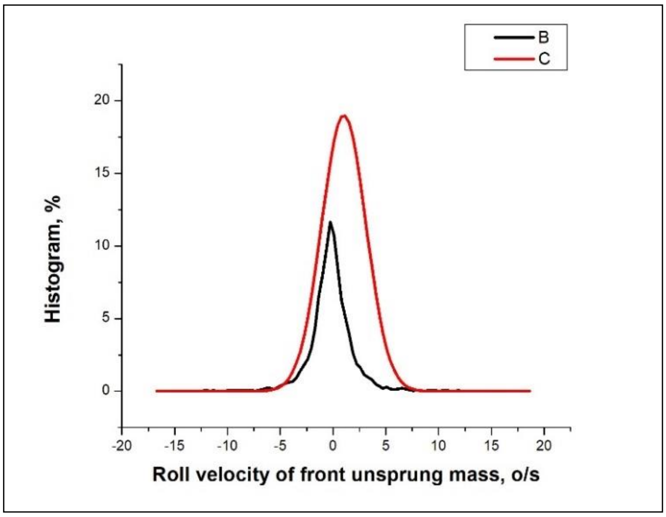


Figure 20 – Gaussian approximation of the rolling angular velocity of the front unsprung mass (B-Experiment, C-Theory)
Рис. 20 – Гауссова аппроксимация угловой скорости качения передней неподрессоренной массы (B-эксперимент, C-теория)
Слика 20 – Гаусова апроксимација угаоне брзине ваљања предње неослоњене масе (B – експеримент, C –теорија)

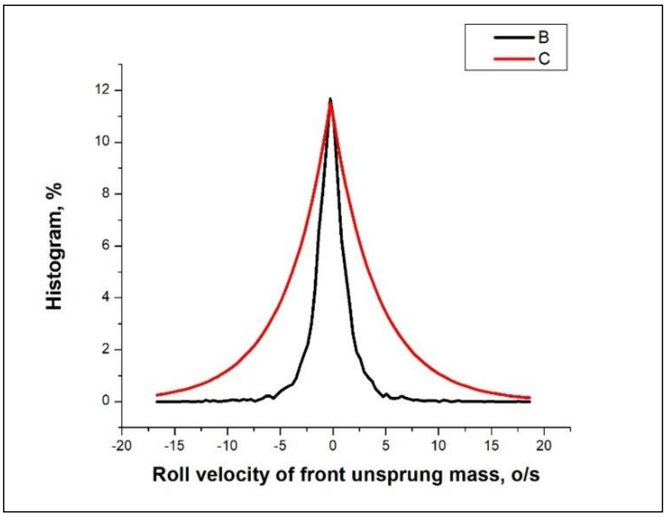


Figure 21 – Laplace approximation of the rolling angular velocity of the front sprung mass (B-Experiment, C-Theory)
Рис. 21 – Аппроксимация Лапласа угловой скорости качения передней неподрессоренной массы (B-эксперимент, C-теория)
Слика 21 – Лапласова апроксимација угаоне брзине ваљања предње неослоњене масе (B – експеримент, C – теорија)

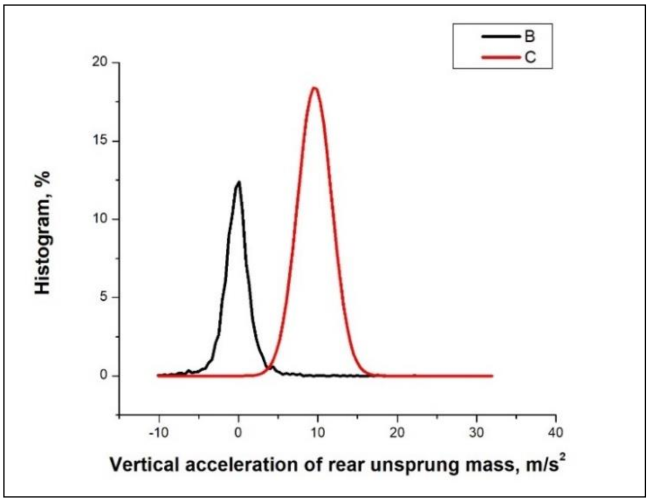


Figure 22 – Gaussian approximation of the vertical accelerations of the front unsprung mass (B-Experiment, C-Theory)
Рис. 22 – Гауссова аппроксимация вертикальных ускорений передней неподрессоренной массы (B-эксперимент, C-теория)
Слика 22 – Гаусова апроксимација вертикалних убрзања предње неослоњене масе (B – експеримент, C – теорија)

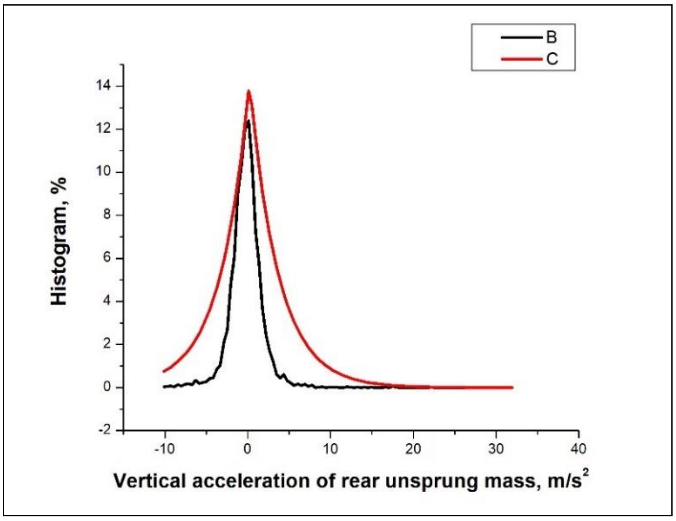


Figure 23 – Laplace approximation of the vertical accelerations of the front unsprung mass (B-Experiment, C-Theory)
Рис. 23 – Аппроксимация Лапласа вертикальных ускорений передней неподрессоренной массы (B-эксперимент, C-теория)
Слика 23 – Лапласова апроксимација вертикалних убрзања предње неослоњене масе (B – експеримент, C – теорија)

Based on the data from Tables 13-15, as well as on illustrative Figures 18-23, it can be considered useful to accept the position that the obtained results can be approximated by the Laplace distribution, in the initial stages of designing laboratory research of heavy motor vehicles.

We note that the Gaussian distribution is defined by two parameters: the mean value and the standard deviation given in Tables 1-3. In this paper, the two-parameter Laplace distribution was used, the parameters of which were identified by the optimization method and given in Tables 16 and 17.

Table 16 – Parameters of the Laplace distribution for the sprung mass: x_1/x_2
Таблица 16 – Параметры распределения Лапласа для подрессоренной массы: x_1/x_2
Табела 16 – Параметри Лапласове расподеле за ослоњену масу: x_1/x_2

Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll angle, º	Pitch angle, º	Veh. velocity, km/h
3.9/2.79	5.1/0.62	5.7/0.0076	15.1/1.57	9.6/0.016	14.6/5.96

Table 17 – Parameters of the Laplace distribution for the unsprung masses: x_1/x_2
Таблица 17– Параметры распределения Лапласа для неподрессоренных масс: x_1/x_2
Табела 17 – Параметри Лапласове расподеле за неослоњене масе: x_1/x_2

	Long. acc. m/s^2	Lat. acc. m/s^2	Vert. acc. m/s2	Roll, o/s	Pitch, o/s	Yaw, o/s
Front	14.1/0.19	6.2/0.0047	6.70/2.63	1.90/0.85	4.30/-0.23	3.20/1.07
Rear	6.60/0.0026	6.0/-0.042	3.50/0.21	4.80/-2.81	3.30/1.24	3.4/2.89

The values from Tables 16 and 17 make it possible to generate the Laplace distribution during laboratory tests.

Based on the results of the performed analyses (the time identification parameters - mean values and autocorrelation function, the amplitude identification parameters - probability density, and the frequency identification parameters - spectra) it is possible to program research in laboratory conditions - on shakers. At the same time, depending on the available types of pulsators, the size that will be reproduced should be selected. Most often, these are vertical oscillations, but it can be some other oscillatory movements (it should be noted that pulsators which can simultaneously generate six excitations are rare).

Conclusion

In order to understand the possibility of creating conditions for testing oscillatory loads of sprung and unsprung masses of heavy vehicles in laboratory conditions, tests were carried out on the FAP 1118 vehicle with 4x4 drive, where the oscillatory parameters were measured in the operating conditions of the vehicle. The measurements for this research and the analysis of the change in vehicle velocity, longitudinal, lateral and vertical acceleration of the front and rear unsprung masses as well as in the roll, pitch and yaw of the front and rear unsprung masses of the vehicle showed that the observed measured values belong to the group of random processes which were identified using time, amplitude and frequency parameter identification. Mean values, autocorrelation functions, amplitude spectra and probability density and mean probability were calculated in the time domain. Frequency analysis was performed using Analsigdem software, observing the magnitude of the calculated spectra of longitudinal, lateral and vertical accelerations and roll, pitch and yaw. Amplitude analysis, i.e. the probability of occurrence of the observed quantity by levels, was performed for all registered quantities.

After the performed analyses, it was determined that there are differences in the levels of the registered sizes for both unsprung and sprung masses. By analyzing all the calculated values of autocorrelation functions, it was determined that they decrease with increasing time delay, or slightly oscillate around the zero value (the exception is the case of velocity), so it can be concluded (Bendat & Piersol, 2000) that all variables, except the vehicle velocity, can be considered stationary and for their identification the theory of stationary random processes can be used. The analyses of all calculated spectrum modules have shown that the highest amplitudes are not unique, but depend on the measurement location (sprung or unsprung mass), as well as on the registered size. In spectrograms, there are usually three areas where extreme values are expressed; therefore, based on (Simić, 1980), it can be claimed that the resonances in the area of 1-2 Hz originate from the sprung mass, the resonances in the area of 9-11 originate from the drive group, and those in the area of 17-24 Hz originate from the unsprung masses. The statistical analysis of the data began with the analysis of the correctness of the adopted Null hypothesis, after which the intervals that meet the probability of 0.95 (the significance level of 0.05) were defined. After this, the hypothesis was tested using the Romanovski test which represents the superstructure for the test χ^2. The analysis of the obtained data found that not a single registered quantity is subject to the Gaussian and two-parameter Laplace distribution, and in most cases, the agreement with the Laplace distribution is better. With an additional check using the Komogorov-Smirnov test, one can accept the position that the obtained results can be approximated by the Laplace distribution, in the initial stages of designing laboratory research of heavy motor vehicles. The values of longitudinal, lateral and vertical acceleration, roll, pitch and vehicle velocity were obtained as the parameters of the Laplace transformation for sprung and unsprung vehicle masses.

Depending on the available types of pulsators in laboratories, but also on the necessary analyses of oscillatory load parameters of sprung and unsprung vehicle masses, it is necessary to choose an adequate size that will be reproduced. Most often, these are vertical oscillations, but it can also be some other oscillatory movement. Values of vertical oscillations are most commonly used since they can be reproduced relatively easily on pulsators with a single excitation. Such laboratory tests in most cases give high-quality results of oscillatory loads of supported and unsupported masses of freight vehicles and are used most often.

For more complex research and experiments, data were obtained for longitudinal and lateral accelerations as well as for angular speeds of rolling and galloping of the supported and unsupported mass of a vehicle. However, the use of all the mentioned quantities in laboratory conditions can be realized by using special pulsators which can generate six excitation types. Such pulsators are rare and are used for complex tests in laboratories.

References

Abe, M. 2009. *Vehicle Handling Dynamics: Theory and Application, 1st Edition.* Oxford, UK: Butterworth-Heinemann. ISBN: 9780080961811.

Bendat, J.S. & Piersol, A.G. 2000. *Random Data: Analysis and Measurement Procedures, 4th Edition*. Hoboken, NJ: John Wiley & Sons. ISBN: 978-0-470-24877-5.

Cox, D.R. & Reid, N. 2000. *The Theory of the Design of Experiments*. Chapman & Hall/CRC. ISBN: 1-58488-195-X.

Demić, M. 1997. *Optimizacija oscilatornih sistema motornih vozila.* Kragujevac, Serbia: Mašinski fakultet (in Serbian). ISBN: 86-81745-40-9.

Demić, M. & Diligenski, Đ. 2003. *The Road Surface Profile Investigation Perspective.* In: *The 30' Session - „Modern technologies in XXI Century*”, Bucharest, Romania, pp.35-42.

Demić, M. 2006. *Dinamičke pobude automobila.* Belgrade, Serbia*:* Institut za nuklearne nauke „Vinča”, Centra za motore i vozila (in Serbian). ISBN: 86-7306-077-X.

Demić, M. 2008. *Kibernetski sistem: čovek - vozilo - okruženje.* Kragujevac, Serbia: Centar za naučna istraživanja SANU i Univerziteta u Kragujevcu (in Serbian). ISBN: 978-86-81037-21-8.

Demić, M., Đurić, A., Grkić, A., Drakulić, M. & Muždeka, S. 2022. A contribution to investigation of oscillatory loads of driving axles in order to create conditions for laboratory tests of trucks. In: *IOP Conference Series: Materials Science and Engineering, Volume 1271, IX International Congress Motor Vehicles and Motors (MVM 2022),* Kragujevac, Serbia, October 13-14. Available at: https://doi.org/10.1088/1757-899X/1271/1/012001.

Demić, M., Toljski, V. & Spentzas, K. 2001. A contribution to investigation of the tire nonuniformity influence to vehicle steering system vibration. *Vojnotehnički glasnik/Military Technical Courier*, 49(3), pp.293-300 (in Serbian). Available at: https://doi.org/10.5937/vojtehg0103293D.

Ellis, J.R. 1969. *Vehicle Dynamics.* Business Books. ISBN 13: 9780220992026.

Fiala, E. 2006. *Mensch und Fahrzeug: Fahrzeugführung und sanfte Technik, ATZ/MTZ Fachbuch*. Vieweg+Teubner Verlag (in German). ISBN-13: 978-3834800169.

Genta, A. 1997. *Motor Vehicle Dynamics: Modeling and Simulation (Advances in Mathematics for Applied Sciences)*. Singapore: World Scientific Publishing Company. ISBN-13: 978-9810229115.

Gillespie, T.D. 1992. *Fundamentals of Vehicle Dynamics.* Warrendale, PA, USA: SAE International. Available at: https://doi.org/10.4271/R-114.

Grkić, A.R. 2015. *Energy potential of friction brake*. Ph.D. thesis. Belgrade, Serbia: University of Belgrade, Faculty of Mechanical Engineering (in Serbian) [online]. Available at: https://nardus.mpn.gov.rs/handle/123456789/5278 [Accessed: 02 March 2023].

Hachaturov, A.A. 1976. *Dinamika sistemy doroga - shina - avtomobil' – voditel'*. Moscow: Mashinostroenie (in Rusian). (In the original: Хачатуров, А.А. 1976. *Динамика системы дорога - шина - автомобиль – водитель.* Москва: Машиностроение).

-ISO. 1995. *ISO 8608:1995 Mechanical vibration — Road surface profiles — Reporting of measured data* [online]. Available at: https://www.iso.org/standard/15913.html [Accessed: 03 March 2023].

Jovanović, S. & Đurić, A. 2009. Analysis of risks from crew exposure to vibrations in military transport. *Vojnotehnički glasnik/Military Technical Courier,* 57(4), pp.93-107 (in Serbian). Available at: https://doi.org/10.5937/vojtehg0904093J.

Milliken, W.F. & Milliken, D.L. 1994. *Race Car Vehicle Dynamics.* Warrendale, PA, USA: SAE International. ISBN: 978-1-56091-526-3.

Mitschke, M. 1972. *Dynamik der Kraftfahrzeuge*. Berlin, Heidelberg: Springer. Available at: https://doi.org/10.1007/978-3-662-11585-5.

Muždeka, S. 2008. *Predviđanje funkcionalnih karakteristika planetarnih prenosnika snage.* Ph.D. thesis. Belgrade, Serbia: University of Belgrade, Faculty of Mechanical Engineering (in Serbian).

O`Connor, P.D.T & Kleyner, A. 2012. *Practical Reliability Engineering*, *Fifth Edition.* Hoboken, NJ: John Wiley & Sons, Ltd. ISBN: 9780470979815.

Rajamani, R. 2006. *Vehicle Dynamics and Control*. New York, NY, USA: Springer. ISBN: 9780387263960.

Simić, D. 1980. *Dinamika motornih vozila*. Belgrade, Serbia: Naučna knjiga (in Serbian).

Vukadinović, S. 1973. *Elementi teorije verovatnoće i statistike.* Belgrade, Serbia: Privredni pregled (in Serbian).

Вклад в исследование колебательных нагрузок подрессоренных и неподрессоренных масс с целью создания условий для лабораторных испытаний грузовых автомобилей

Мирослав Д. Демич[а], *Александр* С. Джурич[б], **корресподент**, *Александр* Р. Гркич[в], *Момир* М. Дракулич[б], *Славко* Муждека[б]

[а] Академия инженерных наук Сербии, г. Белград, Республика Сербия

[б] Университет обороны в г. Белград, Военная академия, департамент военного машиностроения, г. Белград, Республика Сербия

[в] Автомото федерация Сербии, Центр автотранспорта, г. Белград, Республика Сербиа

РУБРИКА ГРНТИ: 55.43.00 Автомобилестроение
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Автомобили представляют собой сложные динамические системы, обусловленные пространственными перемещениями, изменением характеристик деталей в процессе их эксплуатации, большим количеством воздействий и возмущений, появлением люфтов, трения, гистерезиса и т. д. Вышеупомянутые динамические явления, особенно вибрации, вызывают усталость водителя и пассажиров, сокращают срок службы автомобиля и его систем и т. д.

Методы: В основном движение автотранспорта осуществляется по неровным дорогам и криволинейным участкам. Колебательные движения вызывают усталость материала деталей машины, а также оказывают негативное влияние на здоровье людей. Вот почему еще на этапе проектирования автомобиля особое внимание необходимо уделять согласованию взаимодействия движений подсистем, и в частности, системы подвески автомобиля. Для этих целей могут быть использованы теоретические, экспериментальные или комбинированные методы. Именно поэтому очень полезно иметь экспериментальные результаты колебаний подсистемы автомобиля в условиях эксплуатации. Целью данного исследования было использование движения грузового автомобиля ФАП 1118 с полным приводом в условиях *эксплуатации (из-за более высокой скорости в дорожных условиях) для определения условий испытаний колебательных нагрузок в лабораторных условиях.*

Результаты: Это стало возможным благодаря регистрации и идентификации статистических параметров зарегистрированных величин.

Выводы: Основываясь на измеренных данных, исследование можно запрограммировать на пульсаторах в лабораторных условиях и при этом выбрать значения, которые будут воспроизводиться.

Ключевые слова: грузовой автомобиль, подрессоренные и неподрессоренные массы, колебательные нагрузки, лабораторные испытания.

Прилог истраживању осцилаторних оптерећења ослоњене и неослоњених маса ради стварања услова за лабораторијска испитивања теретних моторних возила

Мирослав Д. Демић[а], *Александар* С. Ђурић[б], **аутор за преписку**, *Александар* Р. Гркић[в], *Момир* М. Дракулић[б], *Славко* Муждека[б]

[а] Академија инжењерских наука Србије, Београд, Република Србија

[б] Универзитет одбране у Београду, Војна академија, Катедра војномашинског инжењерства, Београд, Република Србија,

[в] Ауто-мото савез Србије, Центар за моторна возила, Београд, Република Србија

ОБЛАСТ: машинство
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Моторна возила су сложени динамички системи због просторних померања, промене карактеристика компоненти током животног века, великог броја утицаја и сметњи, појаве зазора, трења, хистерезиса итд. Поменуте динамичке појаве, посебно вибрације, изазивају замор возача и путника, смањују век возила и његових система.

Методе: Моторна возила често се крећу по неравном путу и криволинијским путањама у равни пута. Осцилаторна кретања изазивају замор материјала делова возила, али негативно утичу и на здравље људи. Због тога се, још у фази пројектовања моторног возила, мора посветити посебна пажња усаглашавању међусобног кретања подсистема, а посебно система за ослањање возила. У те сврхе могу се користити теоријске, експерименталне или комбиноване методе. Због тога је веома корисно поседовати и експерименталне резултате осциловања подсистема возила у експлоатационим условима. Стога је циљ овог рада био да се

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2023, Vol. 71, Issue 3

кретање возила ФАП 1118, формуле точкова 4x4, у експлоатационим условима (због већих брзина – у условима на путу) искористи за дефинисање услова за испитивање осцилаторних оптерећења у лабораторијским условима.

Резултати: То је омогућено регистровањем и идентификацијом статистичких параметара регистрованих величина.

Закључак: На основу измерених података истраживање се може програмирати на пулсаторима у лабораторијским условима, а истовремено је могуће изабрати величину која ће се репродуковати.

Кључне речи: теретно моторно возило, ослоњене и неослоњене масе, осцилаторна оптерећења, лабораторијска испитивања.

Paper received on / Дата получения работы / Датум пријема чланка: 04.03.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 13.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 15.06.2023.

Numerical analysis of the penetration process of a 30mm armor-piercing projectile

Predrag R. Pantović[a], *Miroslav* M. Živković[b], *Vladimir* P. Milovanović[c], *Nenad* M. Miloradović[d]

[a] University of Kragujevac, Faculty of Engineering, Kragujevac, Republic of Serbia,
e-mail: predragpantovic92@gmail.com, **corresponding author**,
ORCID iD: https://orcid.org/0000-0001-6811-7238

[b] University of Kragujevac, Faculty of Engineering, Kragujevac, Republic of Serbia,
e-mail: miroslav.zivkovic@kg.ac.rs,
ORCID iD: https://orcid.org/0000-0002-0752-6289

[c] University of Kragujevac, Faculty of Engineering, Kragujevac, Republic of Serbia,
e-mail: vladicka@kg.ac.rs,
ORCID iD: https://orcid.org/0000-0003-3071-4728

[d] Ministry of Defense of the Republic of Serbia, Belgrade, Republic of Serbia,
e-mail: nenad.miloradovic@mod.gov.rs,
ORCID iD: https://orcid.org/0009-0006-4123-2627

DOI: 10.5937/vojtehg71-43502; https://doi.org/10.5937/vojtehg71-43502

FIELD: mechanical engineering, materials
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: Thin plates made of high–strength steel are frequently used both in civil and military ballistic protection systems. In order to choose an appropriate type of alloy, it is necessary to fulfil a number of criteria, such as the condition of use, the desired ballistic performance, weight, dimensions, and price. This paper presents a numerical analysis of the penetration of a 30mm armor-piercing projectile with a velocity of 750m/s into steel alloy Weldox 460 plates of different thicknesses at a distance of 1000m .

Methods: The analysis has been performed using numerical methods and finite element modeling to calculate stresses and deformation caused by the penetration effect. For defining material characteristics, the Johnson-Cook material model and the fracture of materials model have been used. In this paper, the software packages FEMAP and LS Dyna have been used for defining models and performing numerical calculations.

Results: The results of the performed numerical analysis as well as the obtained stress and displacement values are presented for four different *armor plate thicknesses: 30mm, 33mm, 34mm, and 40mm. The results show a penetration effect and an interaction between the projectile and the armor plate.*

Conclusion: Modeling the impact on armor-piercing obstacles is very complex, extensive, and demanding, and the formed models approximate the real problem of projectile penetration in a very successful way (or with a certain deviation). In recent times, the analysis using the finite element method has proven to be one of effective approaches to solving such and similar problems. The material and the dimensions of the obstacle, as well as the material and the ballistic parameters of the projectile have the greatest influence on projectile penetration. Keeping all the input parameters at the same level and increasing the thickness of the target leads to its increased resistance to penetration.

Keywords: armor, projectile, penetration, Weldox 460, numerical methods.

Introduction

Studying the effect of impact loads and, as a consequence, the resulting damage in a structure, is very demanding and complex. This stems from the very nature of the process, which is a dynamic event, as well as from the problem of defining the resulting damage.

Ballistic penetration is an extremely complex mechanical process that has been researched for more than 200 years. Today, three different directions of research into the problem of penetration can be defined: empirical, analytical, and numerical.

The empirical approach is based on the formation of appropriate relationships between relevant quantities on the basis of experimentally established dependencies. In contrast, analytical methods are characterized by the development of relatively simple models of the penetration process and the application of relevant equations of movement and material behavior, while the numerical approach is characterized by the discretization of the structure into smaller elements and the application of the fundamental laws of physics to each element individually. Each of the three methods for studying penetration has advantages and disadvantages. Numerical analysis has proven to be capable of determining exact solutions for very complex problems, but it is necessary to invest a lot of time for the required calculations. In most cases, it is best to use a combination of all three approaches. Due to the need for computing resources and the costs of performing a large number of parametric studies, there is a considerable interest in transitional solutions or approximate engineering modeling.

Armor-piercing projectiles are intended to destroy armored targets. They penetrate armor thanks to the enormous kinetic energy they have at the moment of collision with an obstacle and the great endurance of their bodies. The importance of the study of penetration is reflected in its application, which has two aspects. The basic field of application is military technique, considering that penetration is one of the most important mechanisms involved in projectile construction, i.e., terminal ballistics.

The consideration of the penetration process is of fundamental importance for the optimization of projectiles with a penetrating effect, as well as for the design of armor protection. On the other hand, there are also numerous civilian applications of the penetration process, such as the protection of facilities (e.g., nuclear power plants), as well as applications in mining and construction.

In this paper, a numerical simulation of the penetration process of a 30mm anti-aircraft armor projectile into plates made of Weldox 460 alloy of different thicknesses have been done. The drawing of the projectile design used in this analysis is shown in Figure 1.

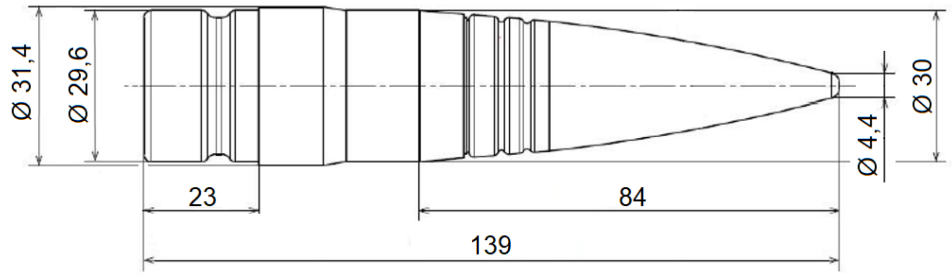


Figure 1 – 30mm projectile, drawing
Рис. 1 – Снаряд 30mm, рисунок
Слика 1 – Пројектил 30 mm, цртеж

The projectile body is made of three different materials:

- Steel *AISI4340* – projectile core,
- Steel *AISI1006* – ballistic cap, and
- Copper – driving ring.

The plate is made of armor steel *Weldox 460*. A 3D model of the projectile design is shown in Figures 2 and 3.

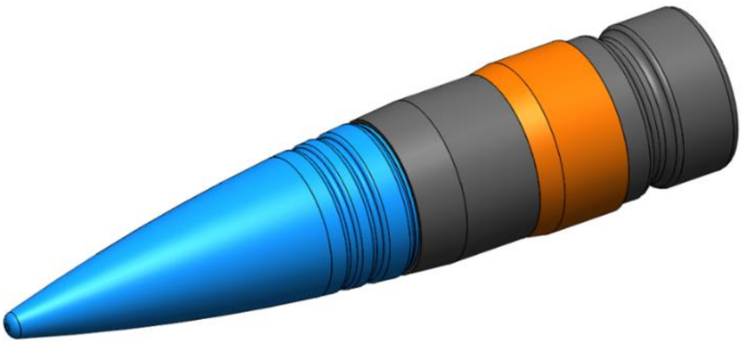


Figure 2 – 30mm projectile, 3D model
Рис. 2 – Снаряд 30mm,3Д модель
Слика 2 – Пројектил 30 mm, модел 3Д

Figure 3 – 30mm projectile parts, 3D model
Рис. 3 – Части снаряда 30мм, 3Д модель
Слика 3 – Делови пројектила 30 mm, модел 3Д

The ballistic characteristics of the projectile are presented in Table 1.

Table 1 – Ballistic characteristics of the 30mm projectile
Таблица 1 – Баллистические характеристики снаряда 30мм
Табела 1 – Балистичке карактеристике пројектила 30 mm

Caliber	d x l	30 x 165	mm
Projectile weight	m	0,4	kg
Projectile velocity (at a distance of 0 m)	V_0	970	m/s
Projectile velocity (at a distance of 1000 m)	V_{1000}	750	m/s
Max pressure at 15°C	P_{max}	< 3500	bar

Theoretical basis

Penetration process

All bodies filled with explosives or some other substance capable of causing a certain effect on the target are called by a common name – ammunition. Today, a large number of different types of ammunition are in use and are distinguished from each other by purpose, shape, structural parameters, launch method, effect on the target, etc.

This type of projectile is used in cannons from 20mm caliber up to the heaviest ones, that is, in all cannons where it is possible to give the projectile such an initial speed that the trajectory is flat, and the impact speed is such that the kinetic energy of the projectile is sufficient to overcome the resistance of a hard obstacle – body armor.

The armor-piercing projectile penetrates the armor thanks to the kinetic energy it has at the moment of collision with the armor and the great endurance of its body.

Penetration, i.e., breaking through, is the process of movement of the penetrator through an obstacle. Every movable body designed for penetration is called a penetrator, and the target body exposed to the influence of a moving penetrator is called an obstacle. The study of the penetration process is of great importance both in the field of civilian application and in the field of military technology.

Terminal ballistics is one of the basic disciplines that deals with the definition of penetration mechanisms, which significantly contributes to the optimization of the design of projectiles with a penetrating and destructive effect, as well as to the design of armor protection.

On the other hand, there are also numerous civilian applications of the penetration process, such as the protection of buildings, etc. Applications for military purposes are certainly a priority and the most important driver of research in the field of penetration (Elek, 2018).

The basic types of penetration processes characteristic of armor-piercing ammunition are shown in Figure 4.

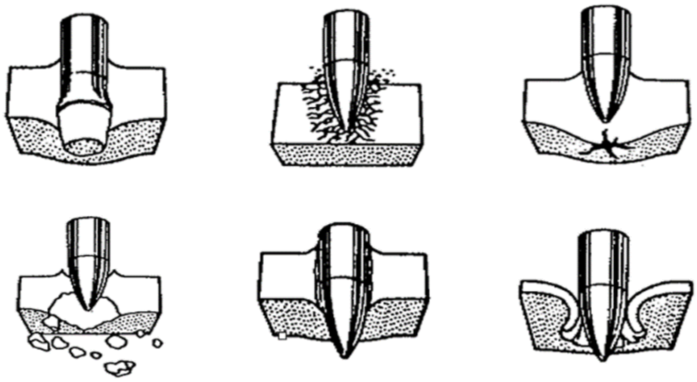


Figure 4 – Basic types of penetration processes
Рис. 4 – Основные типы процессов проникновения
Слика 4 – Основни типови пенетрационих процеса

Depending on the outcome of the penetration process, four different cases are distinguished:

- **Penetration –** implies the passage of the entire penetrator through the obstacle, whereby a regular, approximately cylindrical opening is formed in the obstacle,
- **Limited penetration –** represents the borderline case of penetration because the opening in the obstacle is irregularly shaped and has a smaller area than the area of the cross-section of the penetrator, in contrast to a breakthrough, i.e. only parts of the broken penetrator pass through the opening,
- **Semi penetration –** characterized by stopping (jamming) of the penetrator in an obstacle or breaking it during penetration, and
- **Ricochet** – represents the repulsion of the penetrator due to sliding on the surface of the obstacle if it is inclined.

The penetrating power of a penetrator is the ability to break through an obstacle. Increasing penetrating power of the penetrator can be achieved by increasing the length and density of the penetrator, as well as by reducing its diameter. Conversely, the ability to resist penetration represents the resilience of an obstacle. Increasing the resistance of the obstacle is achieved by increasing its thickness and density, as well as by improving the mechanical characteristics of the material (Elek, 2018).

In the last few years, a large number of papers in the field of ballistic penetration have been published. Some of them contain detailed descriptions and give certain recommendations for various engineering models and numerical techniques, and there are also activities on the development of new models of the penetration process. In addition, great efforts have been made to obtain models and algorithms for simulating the actual response of materials under high-velocity loading. Equations of state and the calculation of strength effects require the definition of constitutive models.

Johnson-Cook material model

Johnson and Cook proposed a semi-experimental constitutive model for metals characterized by high stresses, high strain rates and high temperatures. Each of the phenomena (strain hardening, strain hardening rate and thermal softening) is represented by an independent factor. Taking all factors into account, yield stress is obtained as a function of effective plastic strain, rate of plastic strain and temperature (Wang & Shi, 2013; Liu et al, 2012).

Johnson and Cook represent yield stress by equation 1:

$$\sigma_y = (A + B\bar{\varepsilon}_p{}^n)(1 + cln\dot{\varepsilon}^*)(1 - T^{*m}) \tag{1}$$

where A is the initial yield stress, B is the reinforcement coefficient, n is the amplification exponent, c is the deformation rate constant and m is the thermal softening exponent.

$\bar{\varepsilon}_p$ is the effective plastic deformation and $\dot{\varepsilon}^*$ is the effective plastic strain rate for $\dot{\varepsilon}_0 = 1s^{-1}$ given by equation 2:

$$\dot{\varepsilon}^* = \frac{\dot{\bar{\varepsilon}}_p}{\dot{\varepsilon}_0} \tag{2}$$

Temperature is given by equation 3:

$$T^* = \frac{T - T_{room}}{T_{melt} - T_{room}} \tag{3}$$

where T_{room} is the room temperature and T_{melt} is the material melting temperature.

The constants for materials are determined by various types of tests, such as tensile test, Hopkinson rod test, etc.

The deformation of the material during damage is given by equation 4:

$$\varepsilon^f = [D_1 + D_2\, exp(D_3\sigma^*)](1 + D_4\, ln\, \varepsilon^*)(1 + D_5T^*) \tag{4}$$

where $D_i, i = 1, \ldots, 5$ are the parameters that define the material damage criteria and $\sigma^*$is the ratio of the pressure divided by the effective stress.

Material failure occurs when the parameter (equation 5):

$$D = \sum \frac{\bar{\varepsilon}_p}{\varepsilon^f} \tag{5}$$

reaches the value of 1.

Mie-Grüneisen equation of state

The Mie–Grüneisen equation of state represents the relationship between pressure and volume of a solid at a given temperature. It is used to determine the pressure in solids exposed to high pressure for a short period of time. There are several different relations that define a given dependency. Grüneisen's model can be presented in the form given by equation 6 (Heuzé, 2012; Wilkins, 1999):

$$\Gamma_0 = V\left(\frac{dp}{dE}\right)_V \tag{6}$$

where Γ_0 is the Grüneisen parameter which represents the thermal pressure arising from a set of vibrating atoms, V is the volume, p is the pressure and E is the internal energy.

If it is assumed that Γ_0 does not depend on pressure and internal energy, it can be written (equation 7):

$$p - p_0 = \frac{\Gamma_0}{V}(E - E_0) \tag{7}$$

where p_0 is the reference pressure at a temperature $T = 0K$ and E_0 is the reference internal energy at a temperature $T = 0K$.

In that case, p_0 and E_0 are also independent of temperature, so the values of these parameters can be estimated from Hugoniot's equation-equation 8, 9 and 10 (Heuzé, 2012; Wilkins, 1999).

One version of the equation of state is

$$p = \frac{\rho_0 {C_0}^2 \chi \left(1 - \frac{\Gamma_0}{2}\chi\right)}{(1 - s\chi)^2} + \Gamma_0 E \tag{8}$$

$$\chi = 1 - \frac{\rho_0}{\rho} \tag{9}$$

$$s = \frac{dU_s}{dU_p} \tag{10}$$

where C_0 is the speed of sound through the material, ρ_0 is the initial density of the material, ρ is the current density of the material, Γ_0 is the Grüneisen parameter, s is the linear slope coefficient of Hugoniot's line, U_s is the shock wave speed, U_p is the particle velocity and E is the internal energy per unit of reference volume.

Material characteristics

The Johnson-Cook's parameters for different types of materials used in the numerical simulation of the penetration of a 30mm armor-piercing projectile are defined in Table 2 and the temperature parameters are given in Table 3. In Table 4, the damage parameters for the same materials are defined. These parameters are defining the Johnson–Cook material model used in numerical simulations (Murthy & Santhanakrishnanan, 2020; Bataev et al, 2019; Champagneet al, 2010; Rezasefatet al, 2018).

Table 2 – Johnson–Cook parameters for different materials
Таблица 2 – Параметры Джонсона–Кука для различных материалов
Табела 2 – Џонсон–Кукови параметри за различите материјале

Material	***A [MPa]***	***B [MPa]***	***n***	***C***	***M***
Steel AISI 4340	792	510	0.26	0.014	1.03
Steel AISI 1006	350	275	0.36	0.022	1
Copper	90	292	0.31	0.025	1.09
Weldox 460	490	807	0.73	0.0114	0.94

Table 3 – Thermal characteristics for different materials
Таблица 3 – Тепловые характеристики различных материалов
Табела 3 – Термичке карактеристике за различите материјале

Material	T_{melt} **[K]**	c_p **[J/kgK]**
Steel AISI 4340	1793	477
Steel AISI 1006	1811	450
Copper	1356	383
Weldox 460	1800	452

Table 4 – Damage parameters for different materials
Таблица 4 – Параметры повреждения различных материалов
Табела 4 – Параметри оштећења за различите материјале

Material	D_1	D_2	D_3	D_4	D_5
Steel AISI 4340	0.05	3.44	–2.12	0.002	0.61
Steel AISI 1006	–0.8	2.1	–0.5	0.0002	0.61
Copper	0.54	4.89	–3.03	0.014	1.12
Weldox 460	0.0705	1.732	–0.54	–0.015	0

Table 5 defines the parameters of the equation of state for different materials used in the numerical simulation.

Table 5 – Equation of state parameters for different materials
Таблица 5 – Параметры уравнения состояния различных материалов
Табела 5 – Параметри једначине стања за различите материјале

Material	C_0 **[mm/s]**	**s**	Γ_0
Steel AISI 4340	$3.850 \cdot 10^6$	1.354	1.707
Steel AISI 1006	$3.075 \cdot 10^6$	1.294	1.587
Copper	$3.940 \cdot 10^6$	1.489	1.990
Weldox 460	$3.574 \cdot 10^6$	1.920	1.690

Finite element modeling

The creation of the model using the finite element method is performed on the basis of the existing projectile 3D model. Since the analysis system has two symmetry planes (along the projectile axis), a quarter model is created to obtain faster calculation results. In accordance with the shape and construction of the tested projectiles and the plate, in order to properly define the network, a 3D eight-nodes element type hexa is used. The projectile and plate models are shown in Figures 5, 6 and 7. The finite element model of the projectile is modeled using 141000 nodes and 127000 elements, while the 10mm thick plate is modeled using 1275000 nodes and 1200000 elements. The average size of the elements is 0.5mm.

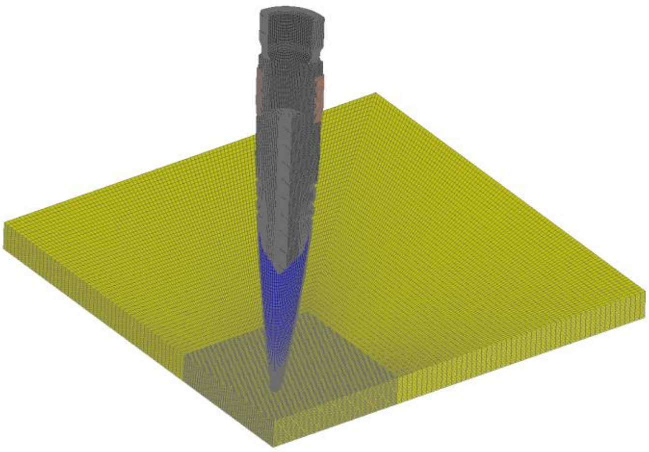


Figure 5 – FEM model of the projectile and the plate, isometry
Рис. 5 – МКЭ-модель снаряда и пластины, изометрия
Слика 5 – МКЕ модел пројектила и плоче, изометрија

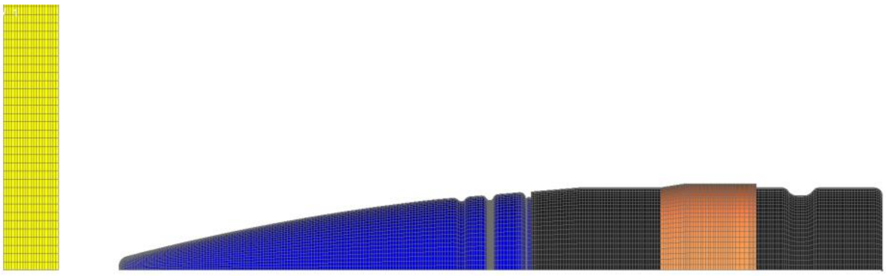


Figure 6 – FEM model of the projectile and the plate, side view
Рис. 6 – МКЭ-модель снаряда и пластины, вид сбоку
Слика 6 – МКЕ модел пројектила и плоче, бочни поглед

Figure 7 – FEM model of the projectile elements
Рис. 7 – МКЭ модель элементов снаряда
Слика 7 – МКЕ модел елемената пројектила

After creating the projectile model and the plate model, the initial and boundary conditions are defined.

Numerical simulation of the penetration process is performed for the value of the projectile impact speed of 750m/s. The reason for choosing this velocity value is that, for 30mm armor-piercing ammunition, penetration is defined at a distance of 1000m from the mouth of the cannon barrel, and the defined velocity of the projectile is a table value at that distance.

Results and discussion

In this chapter, the results for four different cases are presented. Every case represents one plate thickness: 30mm, 40mm and two additional cases for determining the projectile maximum penetration: 33mm and 34mm.

By increasing the thickness of the armor plate, probability that the projectile will have full or partial penetration decreases, and vice versa.

In each case, the constant parameter is the projectile velocity and it has a value of 750m/s.

Case 1 – Plate thickness of 30mm

Figures 8-13 show the Von Misses equivalent stress and penetration effect for armor plate Weldox 460 with a thickness of 30mm.

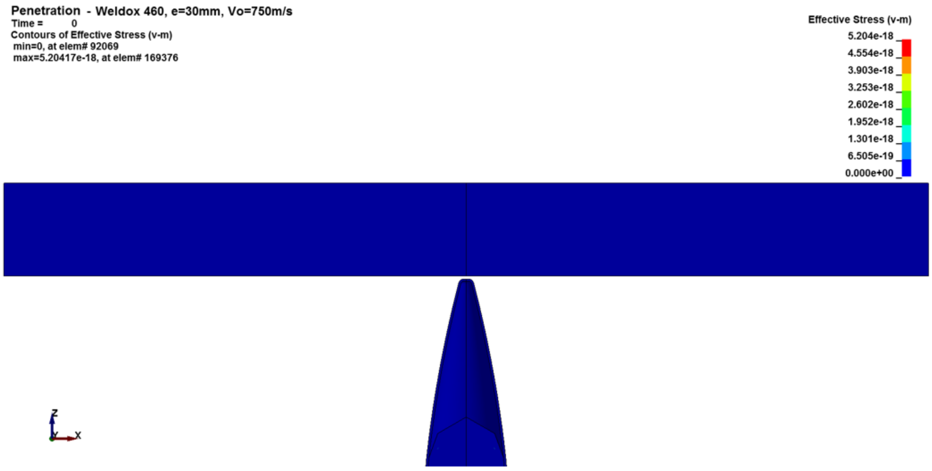


Figure 8 – Von Misses equivalent stress, step 1 – case 1
Рис. 8 – Эквивалентное напряжение Фон Мизиса, шаг 1 – случай 1
Слика 8 – Вон Мисесов еквивалентни напон, корак 1 – случај 1

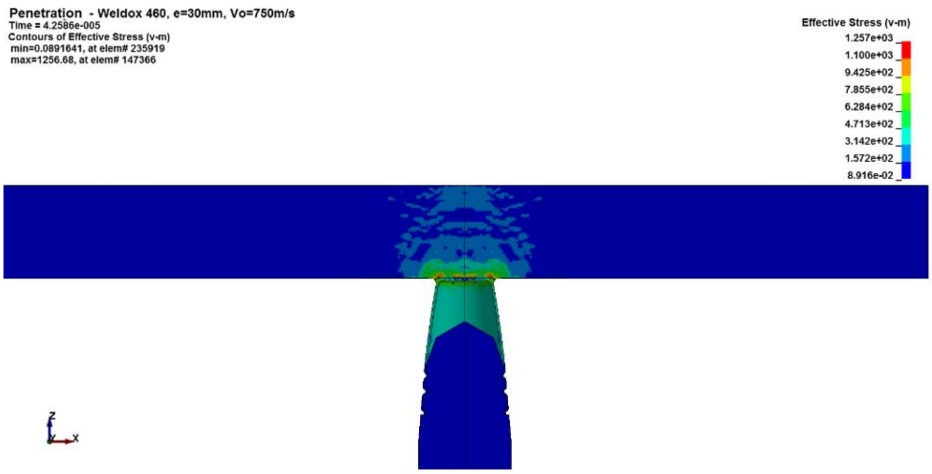


Figure 9 – Von Misses equivalent stress, step 2 – case 1
Рис. 9 – Эквивалентное напряжение Фон Мизиса, шаг 2 – случай 1
Слика 9 – Вон Мисесов еквивалентни напон, корак 2 – случај 1

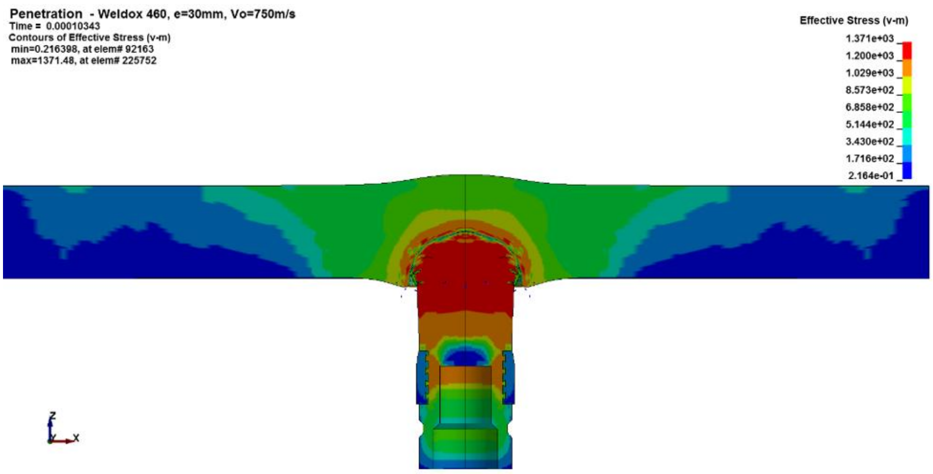


Figure 10 – Von Misses equivalent stress, step 3 – case 1
Рис. 10 – Эквивалентное напряжение Фон Мизиса, шаг 3 – случай 1
Слика 10 – Вон Мисесов еквивалентни напон, корак 3 – случај 1

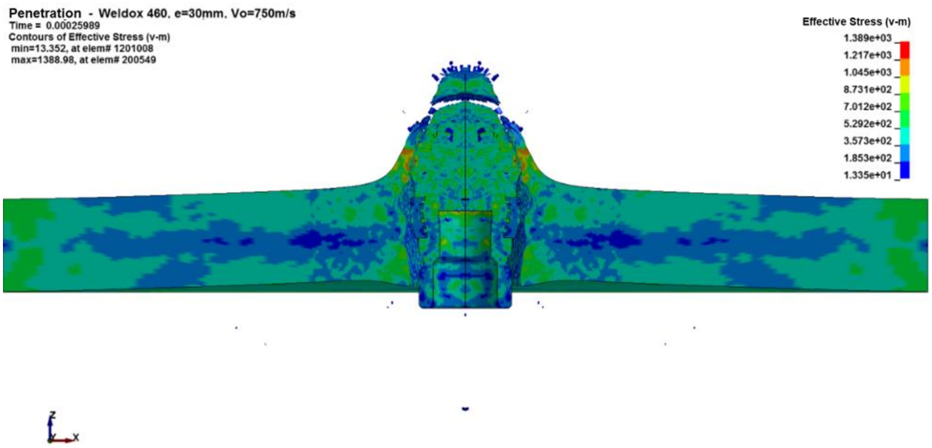


Figure 11 – Von Misses equivalent stress, step 4 – case 1
Рис. 11 – Эквивалентное напряжение Фон Мизиса, шаг 4 – случай 1
Слика 11 – Вон Мисесов еквивалентни напон, корак 4 – случај 1

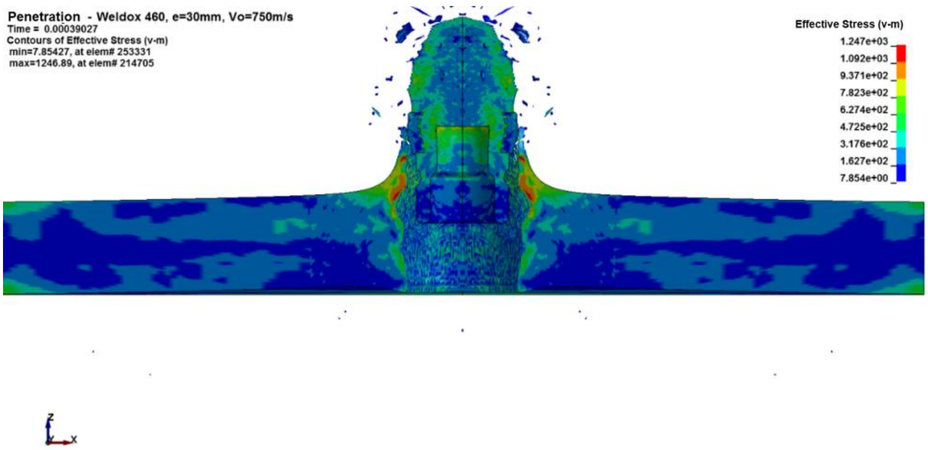


Figure 12 – Von Misses equivalent stress, step 5 – case 1
Рис. 12 – Эквивалентное напряжение Фон Мизиса, шаг 5 – случай 1
Слика 12 – Вон Мисесов еквивалентни напон, корак 5 – случај 1

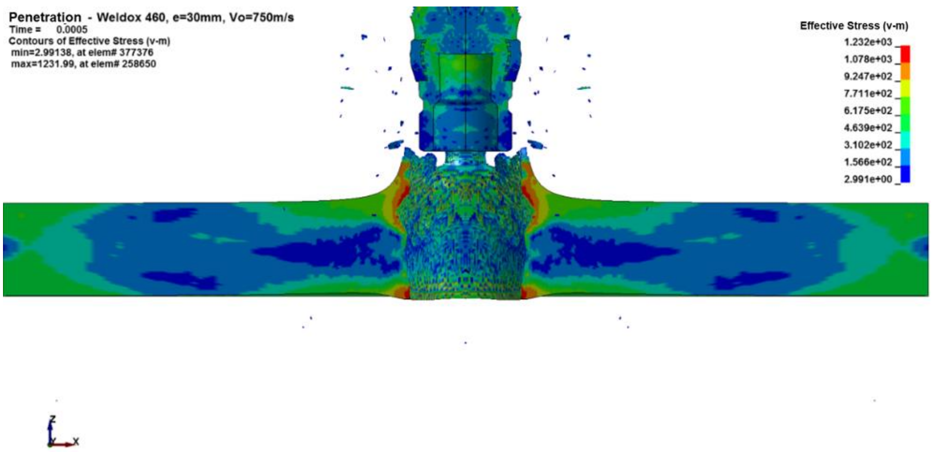


Figure 13 – Von Misses equivalent stress, step 6 – case 1
Рис. 13 – Эквивалентное напряжение Фон Мизиса, шаг 6 – случай 1
Слика 13 – Вон Мисесов еквивалентни напон, корак 6 – случај 1

As the results from Figures 8-13 show, the projectile has sufficient kinetic energy to achieve a full penetration effect in the plate of a thickness of 30mm. A large number of fragments are created behind the armor plate as separated parts of both the projectile and the plate.

Figure 14 shows the projectile velocity from the moment when it starts penetration into the plate until the moment of passing through the plate. The projectile velocity after penetration is 220m/s.

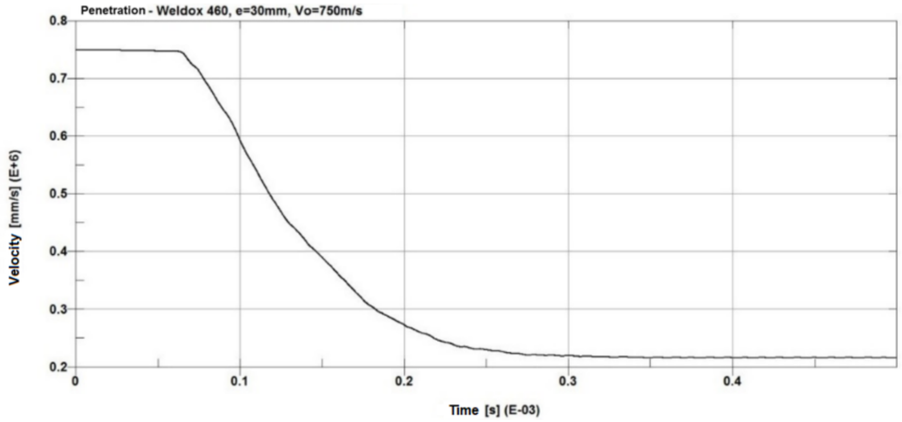


Figure 14 – Projectile speed as a function of time – case 1
Рис. 14 – Скорость снаряда как функция времени – случай 1
Слика 14 – Брзина пројектила у функцији времена – случај 1

Figure 15 shows plate displacement as a function of time. It shows that the first movement of the plate occurs after 0.1ms. The maximum plate displacement is 1.4mm.

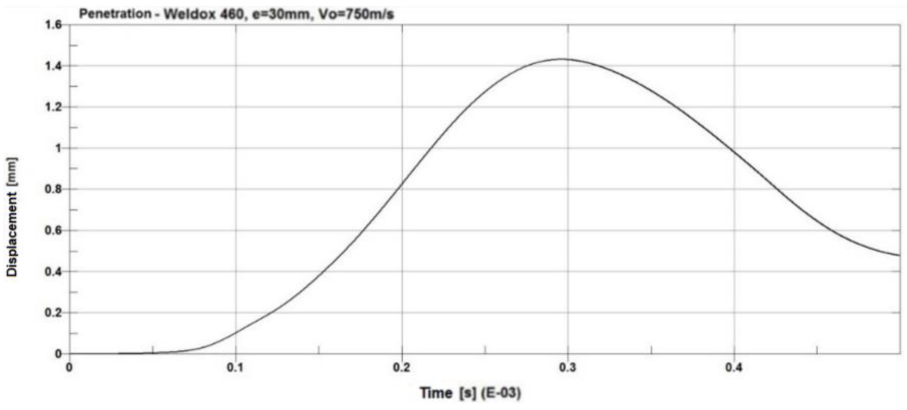


Figure 15 – Plate displacement as a function of time – case 1
Рис. 15 – Смещение пластины как функция времени – случай 1
Слика15 – Померање плоче у функцији времена – случај 1

Case 2 – Plate thickness of 40mm

Figures 16-21 show the Von Misses equivalent stress and penetration effect for armor plate Weldox 460 with a thickness of 40mm.

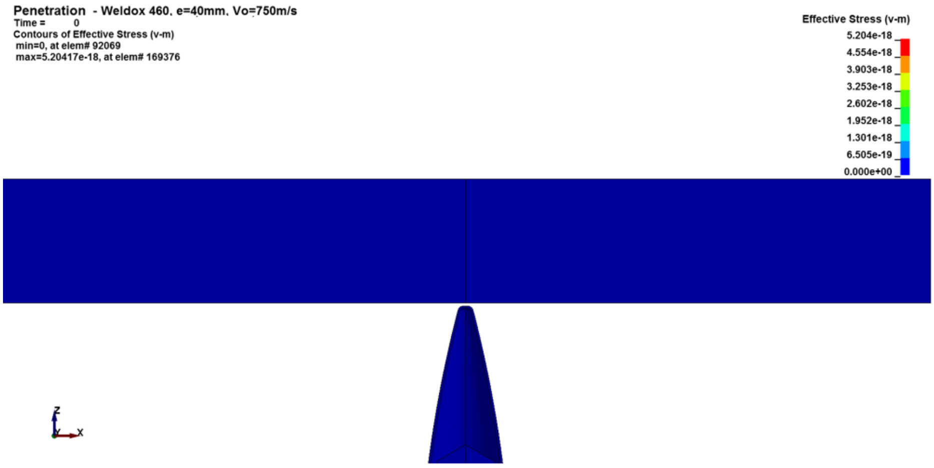


Figure 16 – Von Misses equivalent stress, step 1 – case 2
Рис. 16 – Эквивалентное напряжение Фон Мизиса, шаг 1 – случай 2
Слика 16 – Вон Мисесов еквивалентни напон, корак 1 – случај 2

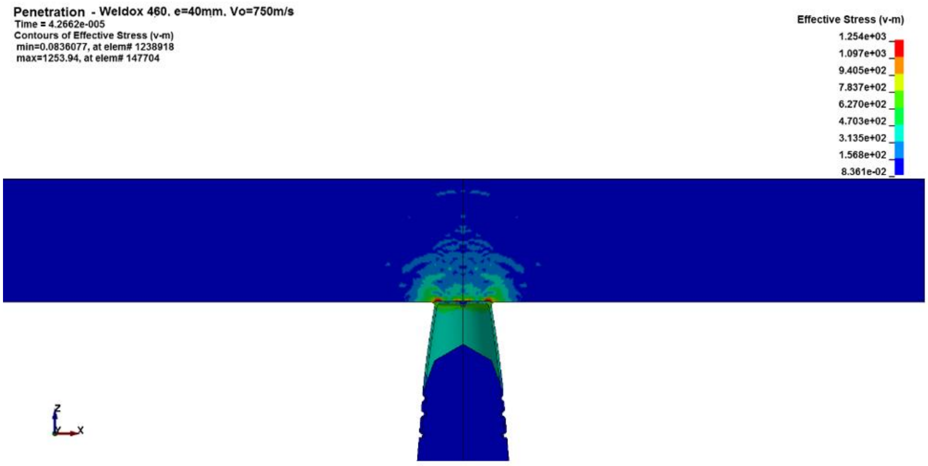


Figure 17 – Von Misses equivalent stress, step 2 – case 2
Рис. 17 – Эквивалентное напряжение Фон Мизиса, шаг 2 – случай 2
Слика 17 – Вон Мисесов еквивалентни напон, корак 2 – случај 2

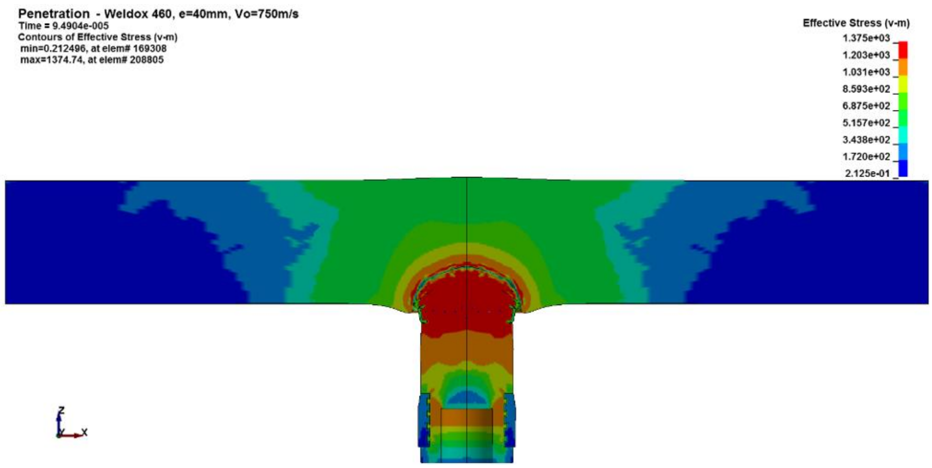


Figure 18 – Von Misses equivalent stress, step 3 – case 2
Рис. 18 – Эквивалентное напряжение Фон Мизиса, шаг 3 – случай 2
Слика 18 – Вон Мисесов еквивалентни напон, корак 3 – случај 2

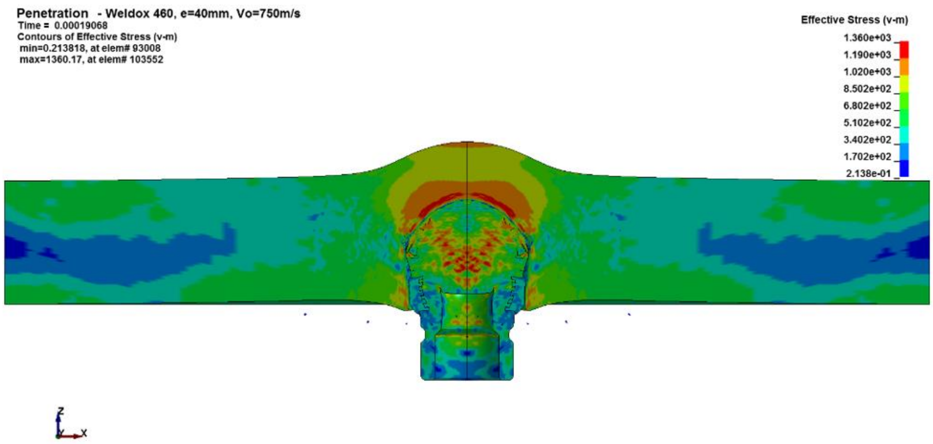


Figure 19 – Von Misses equivalent stress, step 4 – case 2
Рис. 19 – Эквивалентное напряжение Фон Мизиса, шаг 4 – случай 2
Слика 19 – Вон Мисесов еквивалентни напон, корак 4 – случај 2

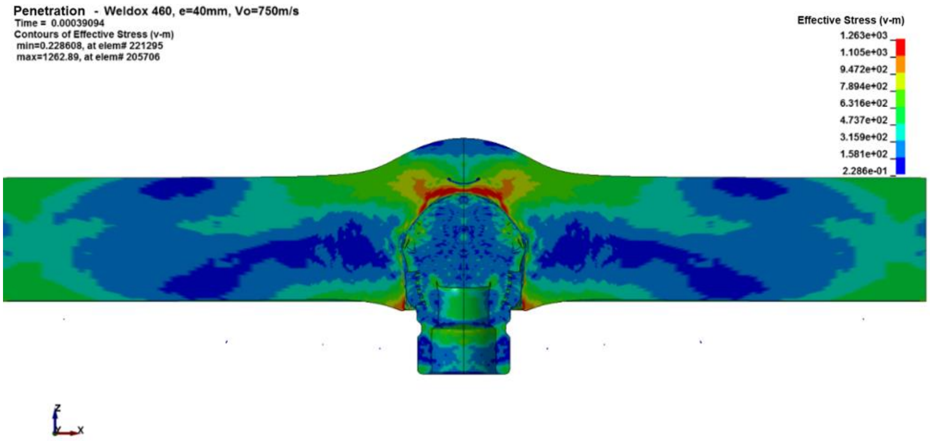


Figure 20 – Von Misses equivalent stress, step 5 – case 2
Рис. 20 – Эквивалентное напряжение Фон Мизиса, шаг 5 – случай 2
Слика 20 – Вон Мисесов еквивалентни напон, корак 5 случај 2

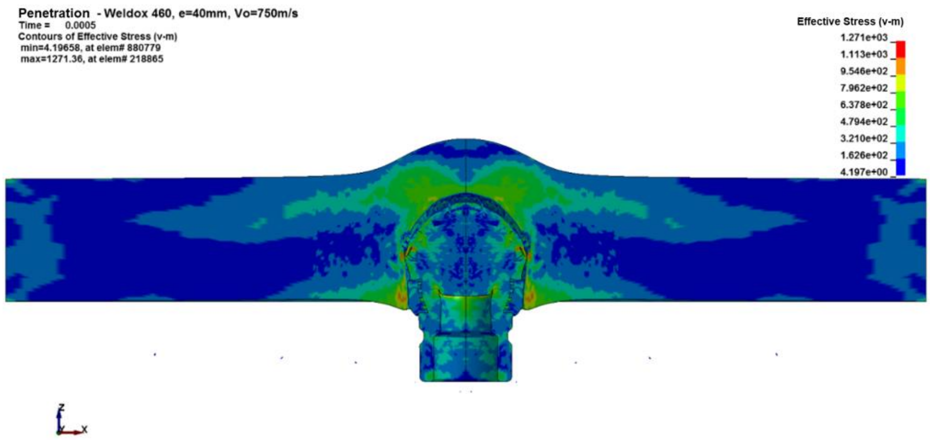


Figure 21 – Von Misses equivalent stress, step 6 – case 2
Рис. 21 – Эквивалентное напряжение Фон Мизиса, шаг 6 – случай 2
Слика 21 – Вон Мисесов еквивалентни напон, корак 6 – случај 2

As the results from Figures 16-21 show, the projectile does not have sufficient kinetic energy to achieve a penetration effect in the plate of a thickness of 40mm. After collision, the projectile jams into the plate.

Figure 22 shows the projectile velocity from the moment when it starts penetration into the plate until the moment when it jams into the plate after 0.24ms.

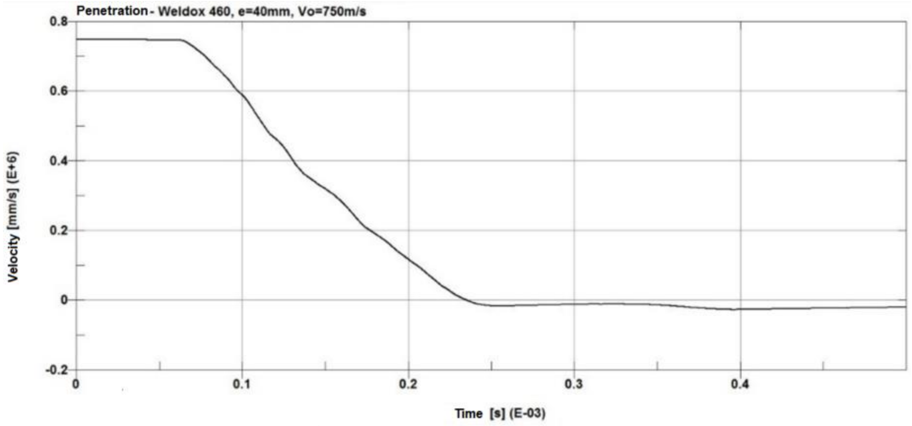


Figure 22 – Projectile speed as a function of time – case 2
Рис. 22 – Скорость снаряда как функция времени – случай 2
Слика 22 – Брзина пројектила у функцији времена – случај 2

Figure 23 shows plate displacement as a function of time. It shows that the first movement of the plate occurs after 0.1ms. The maximum plate displacement is 1mm. It is lower than in case 1 because the plate thickness in case 2 is higher.

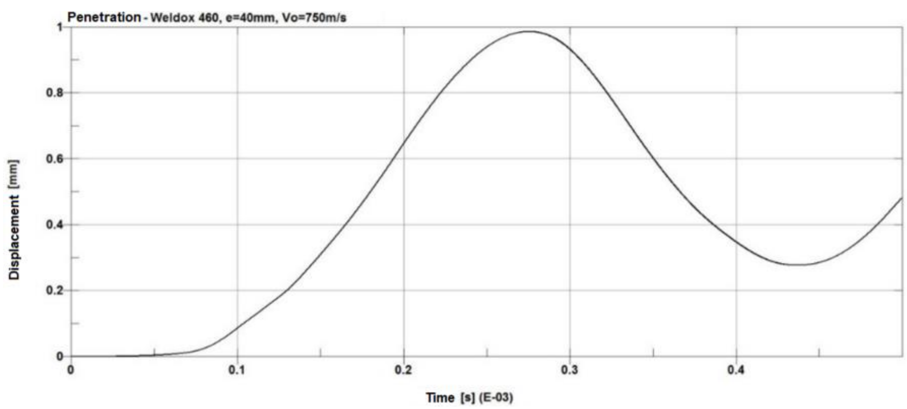


Figure 23 – Plate displacement as a function of time – case 2
Рис. 23 – Смещение пластины как функция времени – случай 2
Слика 23 – Померање плоче у функцији времена – случај 2

Additional cases

After numerical simulation and result analysis, the conclusion is that a 30mm armor-piercing projectile at an impact speed of 750m/s achieves the full penetration effect on 30mm thick plates while in the case of a 40mm thickness, it jams into the plate.

For different purposes, it is of great importance to determine the limit (maximum) plate thickness for which the projectile with defined ballistic and material characteristics is able to achieve the full penetration effect.

For the additional simulation cases, the same input parameters are used for the projectile, and the only difference is the armor plate thickness.

Additional numerical simulations are carried out in accordance with the previously defined models using the same initial and boundary conditions. It is found that the full penetration effect is achieved on plates with a thickness of up to 33mm, and after increasing the thickness to higher values, a limited penetration effect then occurs.

Case 3 – Plate thickness of 33mm

Figures 24-29 show the Von Misses equivalent stress and penetration effect for armor plate Weldox 460 with a thickness of 33mm.

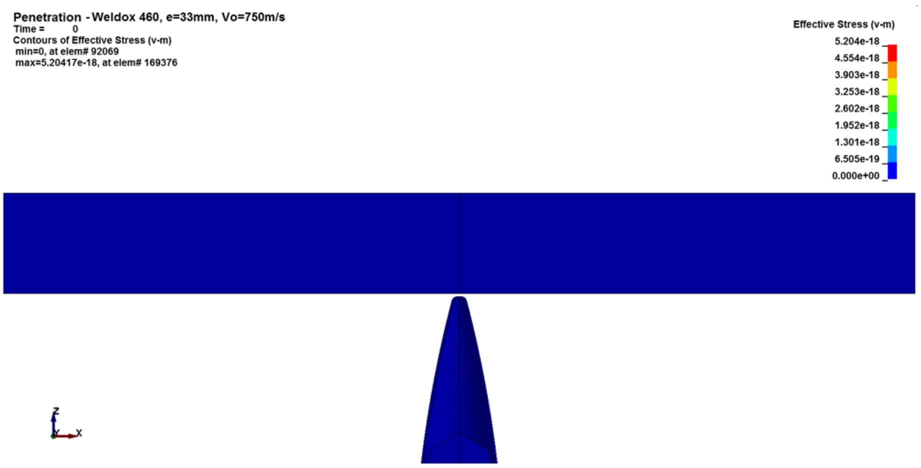


Figure 24 – Von Misses equivalent stress, step 1 – case 3
Рис. 24 – Эквивалентное напряжение Фон Мизиса, шаг 1 – случай 3
Слика 24 – Вон Мисесов еквивалентни напон, корак 1 – случај 3

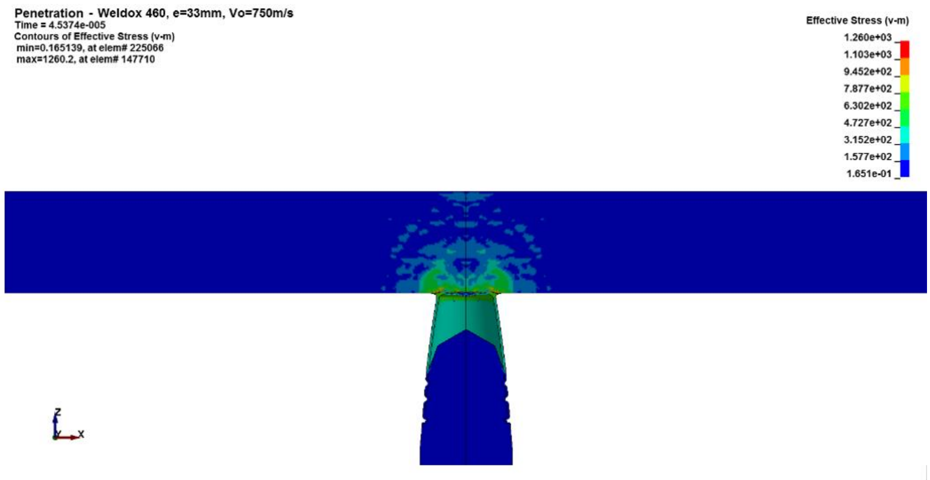


Figure 25 – Von Misses equivalent stress, step 2 – case 3
Рис. 25 – Эквивалентное напряжение Фон Мизиса, шаг 2 – случай 3
Слика 25 – Вон Мисесов еквивалентни напон, корак 2 – случај 3

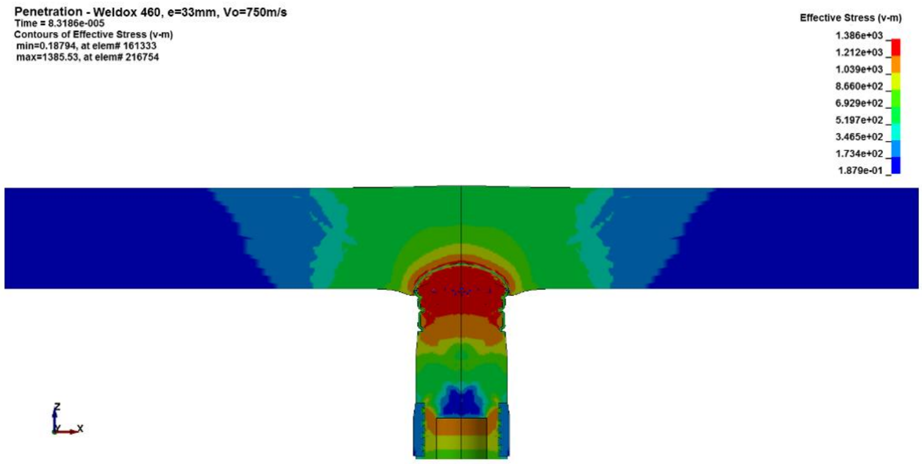


Figure 26 – Von Misses equivalent stress, step 3 – case 3
Рис. 26 – Эквивалентное напряжение Фон Мизиса, шаг 3 – случай 3
Слика 26 – Вон Мисесов еквивалентни напон, корак 3 – случај 3

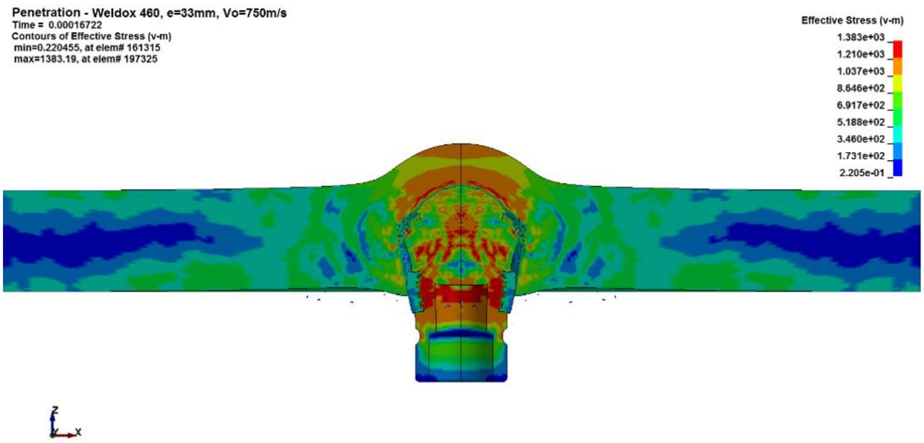


Figure 27 – Von Misses equivalent stress, step 4 – case 3
Рис. 27 – Эквивалентное напряжение Фон Мизиса, шаг 4 – случай 3
Слика 27 – Вон Мисесов еквивалентни напон, корак 4 – случај 3

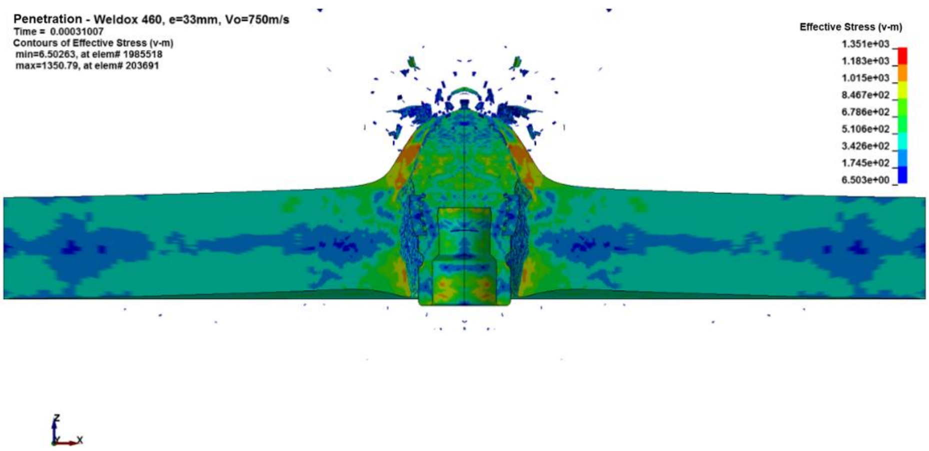


Figure 28 – Von Misses equivalent stress, step 5 – case 3
Рис. 29 – Эквивалентное напряжение Фон Мизиса, шаг 5 – случай 3
Слика 29 – Вон Мисесов еквивалентни напон, корак 5 – случај 3

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2023, Vol. 71, Issue 3

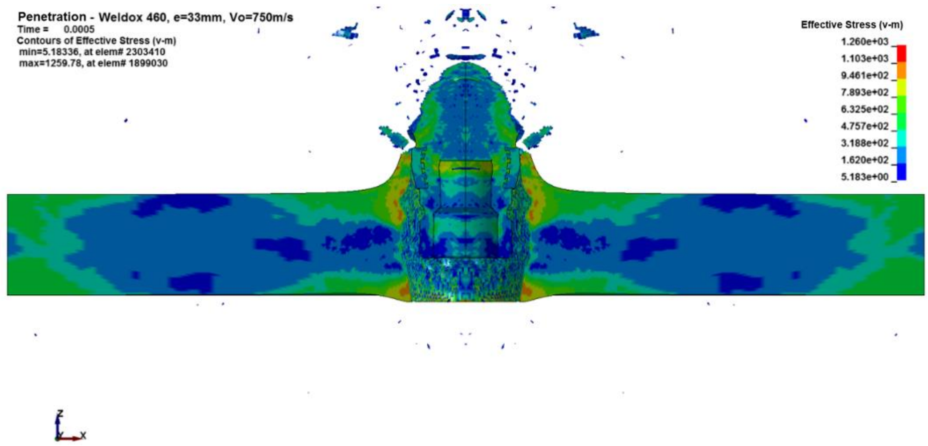


Figure 29 – Von Misses equivalent stress, step 6 – case 3
Рис. 29 – Эквивалентное напряжение Фон Мизиса, шаг 6 – случай 3
Слика 29 – Вон Мисесов еквивалентни напон, корак 6 – случај 3

As the results from Figures 24-29 show, the projectile has sufficient kinetic energy to achieve the full penetration effect in the plate of a thickness of 33mm. A large number of fragments are created behind the armor plate as separated parts of both the projectile and the plate.

Figure 30 shows the projectile velocity from the moment when it starts penetration into the plate until the moment of passing through the plate. The projectile velocity after penetration is 70m/s.

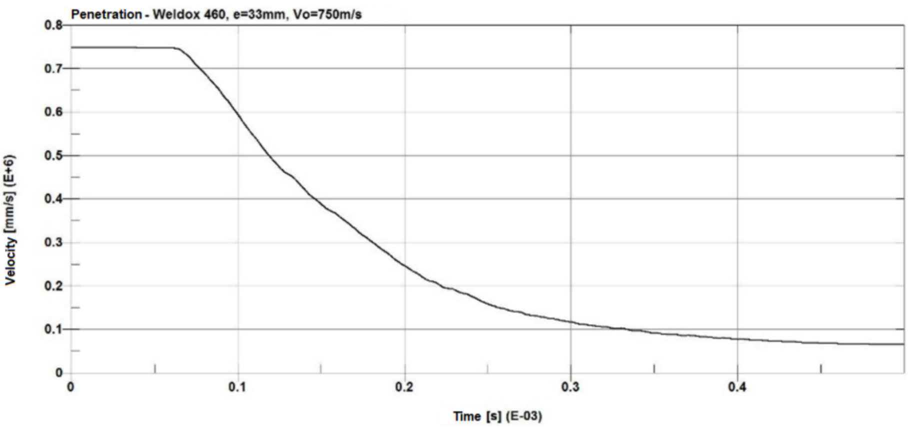


Figure 30 – Projectile speed as a function of time – case 3
Рис. 30 – Скорость снаряда как функция времени – случай 3
Слика 30 – Брзина пројектила у функцији времена – случај 3

Figure 31 shows plate displacement as a function of time. It shows that the first movement of the plate occurs after 0.1ms. The maximum plate displacement is 1.2mm.

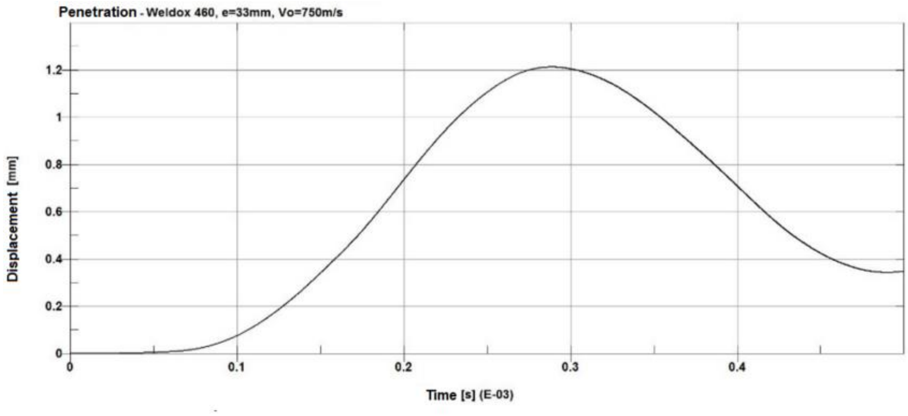


Figure 31 – Plate displacement as a function of time – case 3
Рис. 31 – Смещение пластины как функция времени – случай 3
Слика 31 – Померање плоче у функцији времена – случај 3

Case 4 – Plate thickness of 34mm

Figures 32-37 show the Von Misses equivalent stress and penetration effect for armor plate Weldox 460 with a thickness of 34mm.

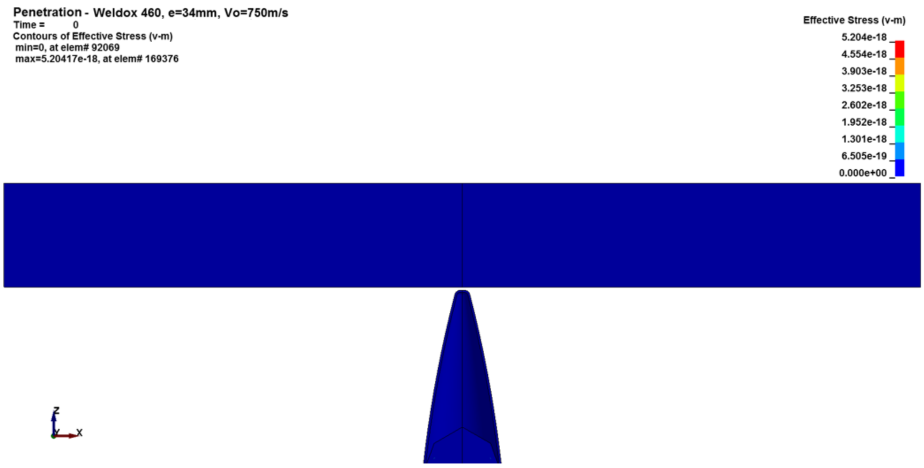


Figure 32 – Von Misses equivalent stress, step 1 – case 4
Рис. 32 – Эквивалентное напряжение Фон Мизиса, шаг 1 – дело 4
Слика 32 – Вон Мисесов еквивалентни напон, корак 1 – случај 4

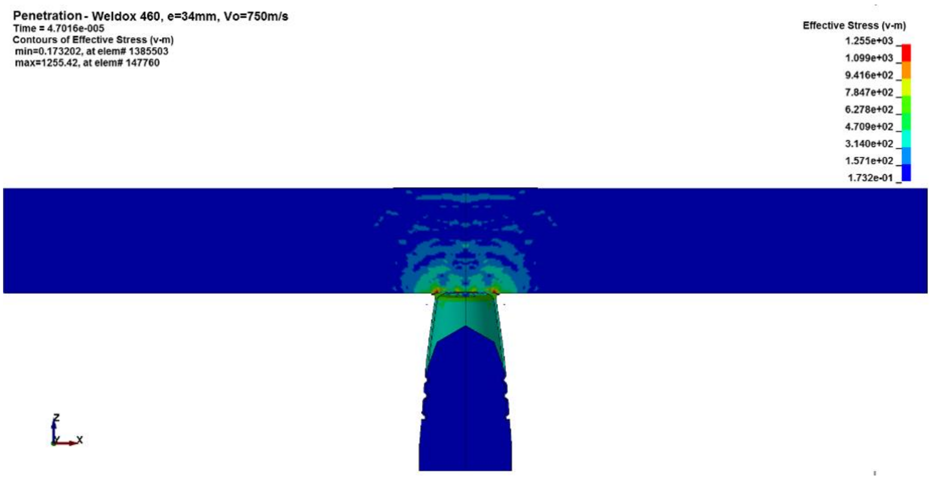


Figure 33 – Von Misses equivalent stress, step 2 – case 4
Рис. 33 – Эквивалентное напряжение Фон Мизиса, шаг 2 – случай 4
Слика 33 – Вон Мисесов еквивалентни напон, корак 2 – случај 4

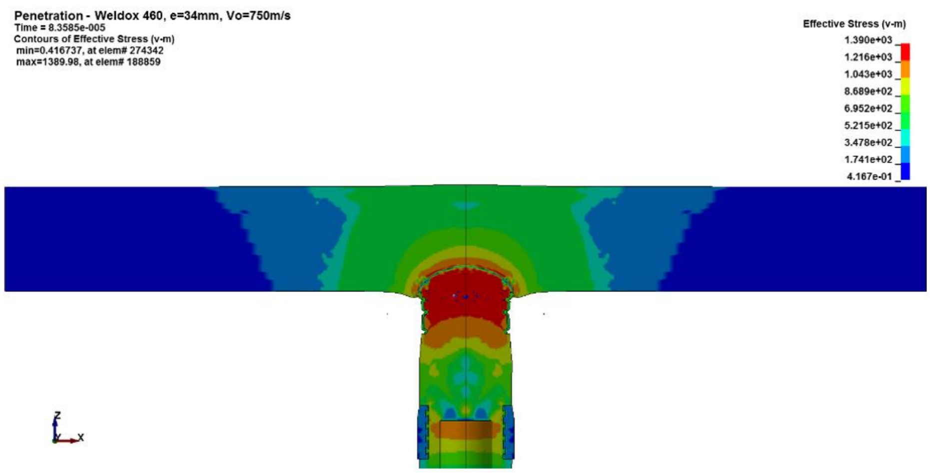


Figure 34 – Von Misses equivalent stress, step 3 – case 4
Рис. 34 – Эквивалентное напряжение Фон Мизиса, шаг 3 – случай 4
Слика 34 – Вон Мисесов еквивалентни напон, корак 3 – случај 4

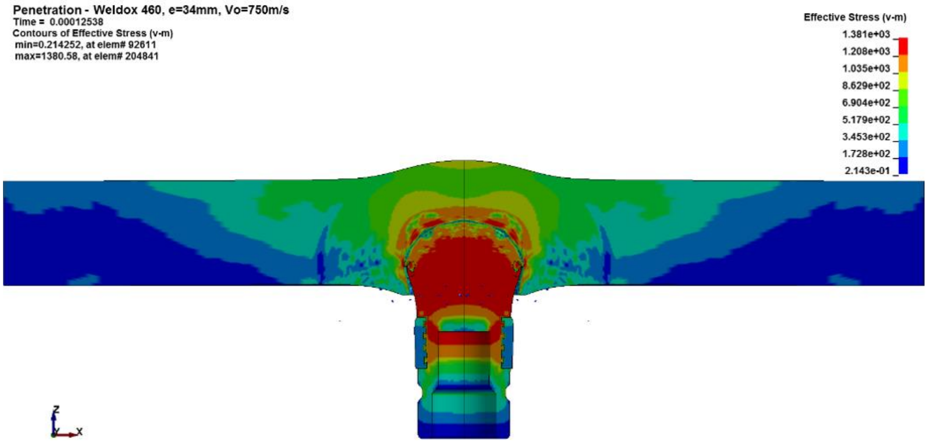


Figure 35 – Von Misses equivalent stress, step 4 – case 4
Рис. 35 – Эквивалентное напряжение Фон Мизиса, шаг 4 – случай 4
Слика 35 – Вон Мисесов еквивалентни напон, корак 4 – случај 4

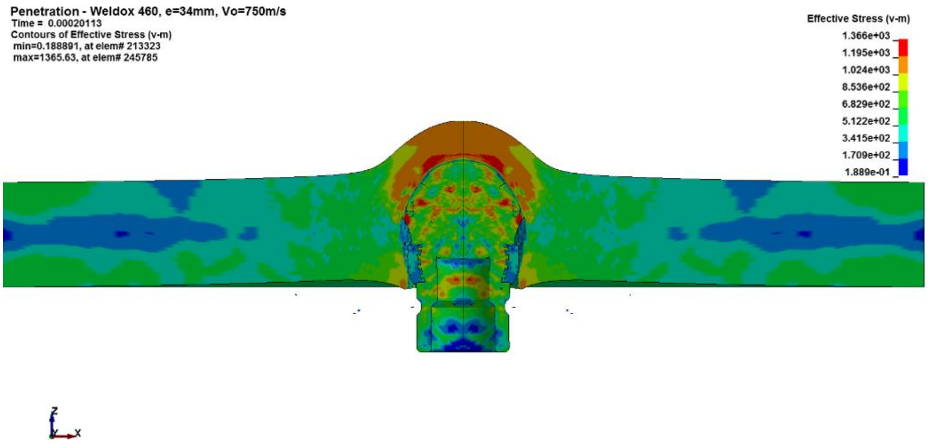


Figure 36 – Von Misses equivalent stress, step 5 – case 4
Рис. 36 – Эквивалентное напряжение Фон Мизиса, шаг 5 – случай 4
Слика 36 – Вон Мисесов еквивалентни напон, корак 5 – случај 4

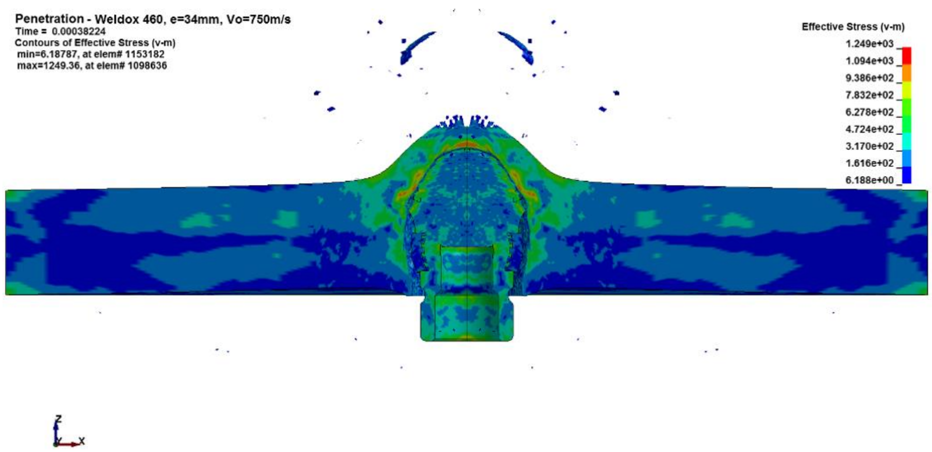


Figure 37 – Von Misses equivalent stress, step 6 – case 4
Рис. 37 – Эквивалентное напряжение Фон Мизиса, шаг 6 – случай 4
Слика 37 – Вон Мисесов еквивалентни напон, корак 6 – случај 4

As the results from Figures 32-37 show, the projectile does not have sufficient kinetic energy to achieve the penetration effect in the plate of a thickness of 34mm. After collision with the plate, the projectile jams into the plate. But, differently from case 2 with the 40mm plate, in this case projectile's semi penetration creates a number of fragments, which can also have a big impact on potential targets behind the plate. Figure 38 shows the projectile velocity from the moment when it starts penetration into the plate until the moment when it jams into the plate after 0.3ms.

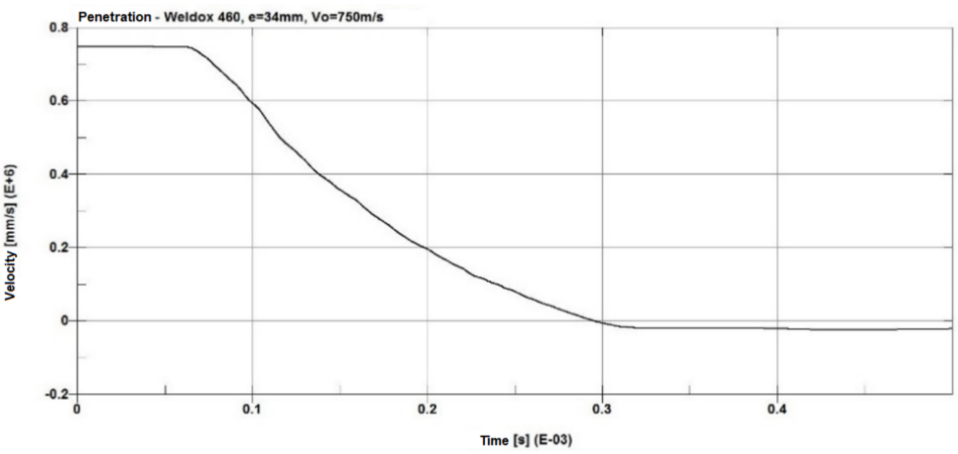


Figure 38 – Projectile speed as a function of time – case 4
Рис. 38 – Скорость снаряда как функция времени – случай 4
Слика 38 – Брзина пројектила у функцији времена – случај 4

Figure 39 shows plate displacement as a function of time. It shows that the first movement of the plate occurs after 0.1ms. The maximum plate displacement is 1.4mm.

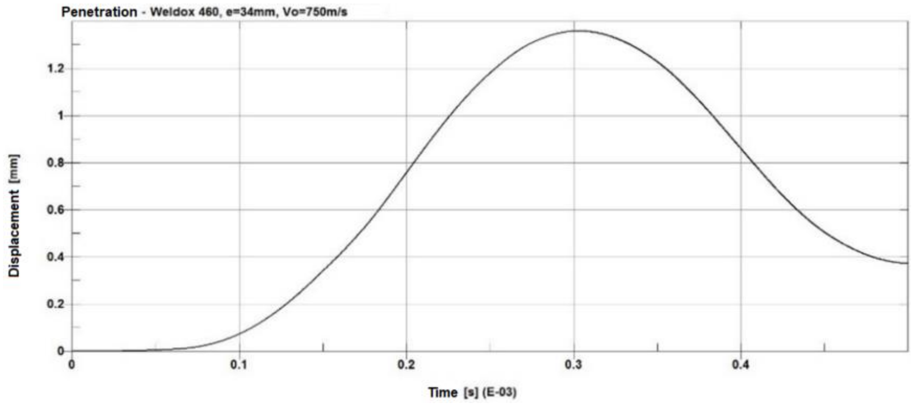


Figure 39 – Plate displacement as a function of time – case 4
Рис. 39 – Смещение пластины как функция времени – случай 4
Слика 39 – Померање плоче у функцији времена – случај 4

Conclusion

Armor-piercing projectiles are designed to penetrate either body armor or vehicle armor. Due to their high kinetic energy at the time of impact with an obstacle and their body’s exceptional endurance, they are able to penetrate armor.

It is extremely difficult to represent the impact of an armor-piercing projectile, but the models created successfully describe the real issue of projectile penetration (or with a certain deviation). In recent times, analysis using the finite element method has proven to be one of effective approaches to solving such and similar problems.

In this paper, a numerical simulation of the penetration process of a 30mm anti-aircraft armor projectile into Weldox 460 alloy plates of different thicknesses was performed. Spasić (2018) has also taken into account the analysis of Weldox 460 armor steel during numerical modeling of a projectile impact on metal structures and shown its behavior when it is in collision with projectiles of different shapes.

Based on a detailed review of the literature, it is found that deformation, strain rate, temperature, and pressure are the key factors that have the greatest influence on the penetration process.

In order to correctly describe these phenomena, it is necessary to define equations of state and models of material behavior. The Johnson–

Cook material model and the Mie–Grüneisen equation of state were used to define the models.

To determine the maximum penetrating ability of the projectile, four simulation cases with different plate thicknesses were performed.

In case 1, with a plate thickness of 30mm, and case 3, with a plate thickness of 33mm, the projectile had the full penetration effect into the defined plates, because the projectile's impact velocity and kinetic energy were higher than needed for the full penetration effect. The projectile velocity behind the plate in case 1 is 220m/s, and in case 3 the velocity is 70m/s.

In case 2, the projectile jammed into the plate with a thickness of 40mm, while in case 4, the projectile jammed into the plate with a thickness of 34mm, but its semi-penetration generated a larger number of fragments behind the plate. In all four cases, the first plate displacements occur after 0.1ms of the analysis.

The projectile with the defined ballistic material and characteristics has the ability to fully penetrate the Weldox 460 plate with a maximum thickness of 33mm.

The calculated ballistic armor steel plate thickness of 33mm is not produced as a standard monobloc plate, but in reality, this thickness can be achieved as a sandwich armor plate with one thicker (e.g., 30mm) and one thinner plate (e.g., 3mm), or with one 30mm plate placed at some angle to the vertical axis.

When defining the ballistic protection of an armored vehicle against projectiles of defined characteristics, it is necessary to use armor steel with a thickness greater than the calculated one in order to neutralize a potential effect of separate fragments from the other side of the plate.

Despite the fact that analytical and numerical methods of calculation can provide correct data about the character of certain phenomena, it is always desirable and necessary, first of all, to carry out experimental tests on the training ground and, after obtaining certain results, to make the necessary corrections and examine the given phenomenon with numerical methods in order to solve the problem more easily and economically.

References

Bataev, I.A., Tanaka, S., Zhou, Q., Lazurenko, D.V., Jorge Junior, A.M., Bataev, A.A., Hokamoto, K., Mori, A. & Chen, P. 2019. Towards better understanding of explosive welding by combination of numerical simulation and experimental study. *Materials & Design*, 169, art.number:107649. Available at: https://doi.org/10.1016/j.matdes.2019.107649.

Champagne, V.K., Helfritch, D.J., Trexler, M.D. & Gabriel, B.M. 2010. The effect of cold spray impact velocity on deposit hardness. *Modelling and Simulation in Materials Science and Engineering*, 18, art.number:065011. Available at: https://doi.org/10.1088/0965-0393/18/6/065011.

Elek, P. 2018. *Balistika na cilju*. Belgrade: University of Belgrade, Faculty of Mechanical Engineering (in Serbian). ISBN: 978-86-7083-966-3 [online]. Available at: https://www.mas.bg.ac.rs/_media/biblioteka/izdanja/17/17.02.pdf [Accessed: 03 March 2023].

Heuzé, O. 2012. General form of the Mie–Grüneisen equation of state. *Comptes Rendus Mécanique*, 340(10), pp.679-687. Available at: https://doi.org/10.1016/j.crme.2012.10.044.

Liu, Z.S., Swaddiwudhipong, S. & Islam, M.J. 2012. Perforation of steel and aluminum targets using a modified Johnson–Cook material model. *Nuclear Engineering and Design*, 250, pp.108-115. Available at: https://doi.org/10.1016/j.nucengdes.2012.06.026.

Murthy, V.C.A.D. & Santhanakrishnanan, S. 2020. Isogrid lattice structure for armouring applications. *Procedia Manufacturing*, 48, pp.e1-e11. Available at: https://doi.org/10.1016/j.promfg.2020.05.099.

Rezasefat, M., Mostofi, T.M., Babaei, H., Ziya-Shamami, M. & Alitavoli, M. 2018. Dynamic plastic response of double-layered circular metallic plates due to localized impulsive loading. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, 233(7), pp.1449-1471. Available at: https://doi.org/10.1177/1464420718760640.

Spasić, D.M. 2018. Numerical modeling of the impact of projectiles on metal structures. *Vojnotehnički glasnik/Military Technical Courier*, 66(1), pp.63-105. Available at: https://doi.org/10.5937/vojtehg66-9604.

Wang, X. & Shi, J. 2013. Validation of Johnson-Cook plasticity and damage model using impact experiment. *International Journal of Impact Engineering*, 60, pp.67-75. Available at: https://doi.org/10.1016/j.ijimpeng.2013.04.010.

Wilkins, M.L. 1999.*Computer Simulation of Dynamic Phenomena.* Heidelberg: Springer Berlin. Available at: https://doi.org/10.1007/978-3-662-03885-7.

Численный анализ процесса проникновения бронебойного снаряда калибра 30-мм

Предраг Р. Пантович[а], **корресподент**, *Мирослав* М. Живкович[а], *Владимир* П. Милованович[а], *Ненад* М. Милорадович[б]

[а] Крагуевацкий университет, факультет инженерных наук, г. Крагуевац, Республика Сербия

[б] Министерство обороны Республики Сербия, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 78.25.00 Вооружение и военная техника
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Тонкие пластины из высокопрочной стали часто используются как в гражданских, так и в военных системах баллистической защиты. При выборе вида сплава, который будет использоваться, необходимо соблюдать ряд критериев, таких как: условия использования, соответствующие баллистические характеристики, вес, размеры и стоимость. В данной статье проведен численный анализ проникновения бронебойного снаряда калибра 30 мм со скоростью 750 м/с с расстояния 1000 м в пластины различной толщины из легированной стали Weldox 460.

Методы: Анализ был выполнен с использованием численных методов и моделирования методом конечных элементов для расчета напряжений и деформаций, вызванных вследствие проникновения. Для определения характеристик материала использовались физическая модель Джонсона-Кука и модель разрушения материалов. В данной статье для утверждения моделей и выполнения численных расчетов использовались программные пакеты FEMAP и LS Dyna.

Результаты: Для определения результатов проведенного численного анализа использовались значения напряжений и деформаций. Представлены также результаты по четырем различным толщинам броневых листов: 30мм, 33мм, 34мм и 40мм. Результаты показывают эффект проникновения и взаимодействие между снарядом и бронепластиной.

Выводы: Моделирование воздействия бронебойных преград очень сложное, объемное и требовательное, а сформированные модели очень удачно (или с некоторым отклонением) аппроксимируют реальную задачу проникновения снаряда. В последнее время анализ с использованием метода конечных элементов является одним из наиболее эффективных подходов к решению подобных задач. Наибольшее влияние на бронепробиваемость снаряда оказывают материал и размеры преграды, а также баллистические параметры снаряда и материалы изготовления. При сохранении всех входных параметров на одном уровне и увеличении толщины мишени увеличивается ее сопротивление к проникновению.

Ключевые слова: броня, снаряд, проникновение, Weldox 460, численные методы.

Нумеричка анализа процеса пенетрације панцирног пројектила 30 mm

Предраг Р. Пантовић[а], **аутор за преписку**, *Мирослав* М.Живковић[а], *Владимир* П. Миловановић[а], *Ненад* М. Милорадовић[б]

[а] Универзитет у Крагујевцу, Факултет инжењерских наука, Крагујевац, Република Србија

[б] Министарство одбране Републике Србије, Београд, Република Србија

ОБЛАСТ: машинско инжењерство, материјали
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Танке плоче од челика високе чврстоће често се користе у цивилним и војним системима балистичке заштите. За одабир врсте легуре која ће се користити потребно је испунити низ критеријума, као што су услови употребе, жељене балистичке перформансе, тежина, димензије и цена. У раду је урађена нумеричка анализа пробојности панцирно-пробојног пројектила калибра 30 mm, брзине 750 m/s, на удаљености од 1000 m, у плоче различите дебљине од легуре челика Weldox 460.

Методе: Анализа је извршена нумеричким методама и моделирањем коначних елемената за прорачун напона и деформација узрокованих ефектом пробојности. За дефинисање карактеристика материјала коришћен је Џонсон-Куков материјални модел и модел лома материјала, а за дефинисање модела и извођење нумеричког прорачуна коришћени су софтверски пакети FEMAP и LS Dyna.

Резултати: За дефинисање резултата извршене нумеричке анализе коришћене су вредности напона и деформација. Приказани су резултати за четири различите дебљине оклопних плоча: 30 mm, 33 mm, 34 mm и 40 mm. Показан је ефекат пенетрације и интеракција између пројектила и оклопне плоче.

Закључак: Моделовање утицаја оклопних препрека је веома сложено, обимно и захтевно, а формирани модели на веома успешан начин (или са одређеним одступањем) апроксимирају стварни проблем продора пројектила. Анализа методом коначних елемената се, у новије време, показала као један од ефикаснијих приступа за решавање оваквих и сличних проблема. Материјал и димензије препреке, као и материјални и балистички параметри пројектила, имају највећи утицај на продор пројектила. Одржавањем свих улазних параметара на истом нивоу, и повећањем дебљине мете, повећава се и њен отпор на продор.

Кључне речи: оклоп, пројектил, продор, Weldox 460, нумеричке методе.

Paper received on / Дата получения работы / Датум пријема чланка: 04.04.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 14.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 16.06.2023.

Evaluation of low-temperature properties of mixtures of bitumen and SBS polymers of various topologies by the ABCD method

Vladimir E. Nikolaevsky[a], *Pavel* A. Duzhiy[b], *Dmitry* Yu. Nebratenko[c]

[a] Russian University of Transport, Institute of Roads, Construction and Structures, Department of Highways, Airfields, Base and Foundations, Moscow, Russian Federation,
e-mail: ve_nikolaevskiy@mail.ru,
ORCID iD: https://orcid.org/0009-0008-4939-6014

[b] MIREA-Russian Technological University, Institute of Fine Chemical Technologies named after M.V. Lomonosov,
Department of Chemistry and Technology of Elastomer Processing, Moscow, Russian Federation,
e-mail: palladiy2002@yandex.ru,
ORCID iD: https://orcid.org/0009-0008-1488-5264

[c] Russian University of Transport, Institute of Roads, Construction and Structures, Department of Highways, Airfields, Base and Foundations;
MIREA-Russian Technological University, Institute of Fine Chemical Technologies named after M.V. Lomonosov,
Department of Chemistry and Technology of Elastomer Processing, Moscow, Russian Federation,
e-mail: nebratenko@mail.ru, **corresponding author**,
ORCID iD: https://orcid.org/0000-0002-3607-8876

DOI: 10.5937/vojtehg71-44548; https://doi.org/10.5937/vojtehg71-44548

FIELD: chemical technology, chemical industry, construction, architecture
ARTICLE TYPE: original scientific paper

Abstract:

Introduction: Due to climate change, scientists around the world, including specialists in the road construction industry, are forced to take into account the need for regular monitoring of the low-temperature properties of both individual building materials and the properties of multicomponent road composites based on them. Therefore, the possibility of developing new approaches and methods for evaluating these properties is being studied.

Methods: For these purposes, Dr. Kim Sang-Soo proposed a new method for evaluating the low-temperature properties of road binders, which was called the ABCD (Asphalt Binder Cracking Device) method. The use of the device does not require special skills and knowledge and auxiliary equipment is widely available in laboratories of road construction organizations. The duration of the test does not exceed 4-5 hours.

Results: The possibility and effectiveness of regulating the cracking temperature of bitumen-containing binders by introducing styrene-butadiene thermoplastics of various topologies into the composition is shown using the example of industrially produced batches of petroleum road viscous oxidized bitumen and applying the ABCD methodology.

Conclusions: In Russia, where winter temperatures in the vast majority of the country fall below minus 30 degrees Celsius, it is extremely important to control the behavior of bitumen binders and multicomponent mixtures of different compositions (asphalt concrete mixtures). The national standard GOST R 58400.11-2019 has been put into effect and the production of appropriate measuring equipment has been established. At the same time, the ABCD method can be used both to study the properties of mixtures of binders with polymers of various topologies and to select a commercial binder that meets the requirements of a specific region of highway operation.

Keywords: cracking temperature, polymer-modified bitumen, ABCD method, styrene-butadiene thermoplastics of various topologies.

Introduction

Low-temperature cracking of asphalt pavement is understood as transverse cracks occurring at approximately equal distances at right angles to the direction of travel (Flory, 1985). It is assumed that binders with higher stiffness will crack at higher temperatures than softer bituminous binders (Gokhman, 1977; Nazzal et al, 2014; Petersen et al, 1994; Plewa, 2019).

To date, no sound methodology or direct measurement method has been developed in the world that can accurately determine the low-temperature properties of binders based on tests performed at much higher temperatures, such as under normal conditions.

That is why of great practical interest are the so-called direct measurement methods which reproduce the loading conditions of materials or structures as close to reality as possible. The data obtained in the course of such tests are a reliable basis for predicting the real performance properties of both raw material components and multicomponent materials based on them.

An example is the ABCD (Asphalt Binder Cracking Device) method of evaluating the low-temperature properties of road bitumen, developed during many years of research by Dr. Kim Sang-Soo, a professor in the Department of Civil Engineering at Ohio University (Kim, 2005, 2007; Petersen 1994).

The feature of this fundamentally new for the Russian road industry test method is the ability to determine the potential of low-temperature cracking of bitumen binders without prior analysis or knowledge of the rheological properties of bitumen binders (Nebratenko, 2022).

When the temperature of the pavement decreases under actual operating conditions, shrinkage and cracking of the asphalt concrete pavement as a whole and, above all, of bituminous binders, takes place. In this case, the binder acts as a glue in the composition of the pavement and, under certain conditions, the monolithic adhesive layer between the particles of stone aggregate is broken.

The ABCD test is carried out as follows: a sample of a bituminous (often polymer-bitumen) binder is placed in a cryochamber and the temperature of the air surrounding the tested sample is gradually reduced, causing similar thermal compression until a transverse crack is formed (Nebratenko & Nikolaevsky, 2023).

Methodology for assessing the properties of mixtures based on semi-blown road bitumen and SBS polymers

Let us illustrate the possibility of assessing the low-temperature properties of mixtures based on semi-blown (oxidized) oil road bitumen and SBS-polymers of different molecular structures by the ABCD method. This will make it possible to evaluate the advantages of a number of modifiers used to improve the low-temperature properties of road binders.

Bitumen basic compositions were industrially produced oil oxidized road bitumen BND 70/100, conforming to GOST 33133-2014 (Table 1).

Table 1 – Physical and mechanical properties of semi-blown viscous road petroleum bitumen

Таблица 1 – Физико-механические свойства битума нефтяного дорожного вязкого окисленного

Табела 1 – Физичко-механичка својства нафтног путног вискозног оксидованог битумена

№	Name of the indicator	Actual values for BND 70/100	Test methods of bitumen (Interstate standard, GOST)
1	Penetration at the temperature of 25°C, [0.1 mm]	90	GOST 33136
2	Penetration at the temperature of 0°C, [0.1 mm]	34	GOST 33136
3	Ductility at 25°C, [cm]	90	GOST 33138
4	Softening point (ring and ball), [°C]	50	GOST 33142
5	Fraass breaking point, [°C]	- 18	GOST 33143
6	Flash point (Cleveland open cup), [°C]	271	GOST 33141

Polymers in the amount of 3% wt. were introduced in equal portions into the base bitumen heated to a temperature of 140-160°C. During the first 15 minutes, the mixture was mixed with a laboratory dispersant IKA Ultra-Turrax T25 digital at a rotor speed of about 10,000 revolutions per minute. Then the aging stage (swelling) took place for 2.5 hours at a rotor speed of 3,000 revolutions per minute and a temperature of 60-80°C.

The ABCD cracking machine is one of the few devices that determine the indicator of the binder not indirectly, but by a direct method. This significantly differs, for example, from the well-known method “Ring and Ball” according to GOST 11506 or GOST 33142.

The measuring part of the device consists of a metal ring of Invar, equipped with temperature and deformation sensors, The metal ring with sensors is placed in an elastic silicone rubber shell (Fig. 1). After the heated bitumen binder is poured into the gap between the ring and the casing and solidifies, the samples (one control and three test samples) are placed in a cryochamber (Kim, 2007; Nebratenko & Nikolaevsky, 2023).

Figure 1 – ABCD sensors during (left) and after (right) testing of binders
Рис. 1 – Датчики ABCD во время (слева) и после (справа) проведения испытаний вяжущих
Слика 1 – АБСД сензори током (лево) и након (десно) тестирања везива

When the temperature drops, the bitumen binder shrinks more than the metal ring of Invar. Invar is a specially selected alloy composed of nickel (Ni, 36%) and iron (Fe, 64%) and has a uniquely low coefficient of thermal expansion. This makes it possible to keep its geometrical dimensions unchanged in the widest temperature range from minus 90 up to plus 250°C. Invar's coefficient of thermal expansion is only 1.2·10-6 °C (Nebratenko, 2022).

When bitumen or the binder cools, thermal deformations lead to changes in the strength, stiffness and thermal compression coefficient. The temperature and stress level at which the continuity of the test samples is broken are recorded automatically. This makes it possible to determine the degree of suitability of the investigated binder type for its use in the course of construction or repair of road surfaces in the natural and climatic conditions of subsequent operation expected in a particular region of Russia as reliably as possible.

The results of measurements of the studied parameters reflecting the low-temperature properties of road bitumen binders of different types, including those containing SBS-polymers, are presented in Table 2.

Table 2 shows the low-temperature values determined by the ABCD method for several binders, including SBS-polymer-based PMBs of different structures.

Table 2 – Low-temperature indicators of bituminous binders
Таблица 2– Низкотемпературные показатели битумных вяжущих
Табела 2 – Нискотемпературни показатељи битуменских везива

Binder	Cracking temperature of ABCD, °C	Fraass breaking point, °C	Deformation spike, µε	Breaking stress, MPa
BND70/100	-36.41	-18	16.58	2.61
PMB 60 to SBS-330L	-44.96	-24	31.27	5.05
PMB 60 to SBS-330B	-41.14	-22	20.05	3.48

The 15-30% decrease in the cracking temperature for ABCD polymer-bitumen compared to the data for basic bitumen can be explained by the presence of a three-dimensional elastomeric mesh in the volume of polymer-bitumen binder. There is, due to its presence, a dissipation of deformations resulting from temperature stresses during cooling of the binder.

The graph in Fig. 2 shows that when the temperature drops below minus 30°C, excessive residual temperature deformations accumulate in the volume of the PMB, the dissipation of which even in elastic blocks of SBS polymers is prevented by the low rate of relaxation. It should be noted that cooling of the system is carried out at rather low speeds corresponding to the requirements of GOST R 58400.11-2019 “Public Roads, Petroleum Bituminous Binder Materials, Method for Determining the Cracking

Temperature Using the ABCD Device" and corresponding to the actual operating conditions in the regions of the Russian Federation.

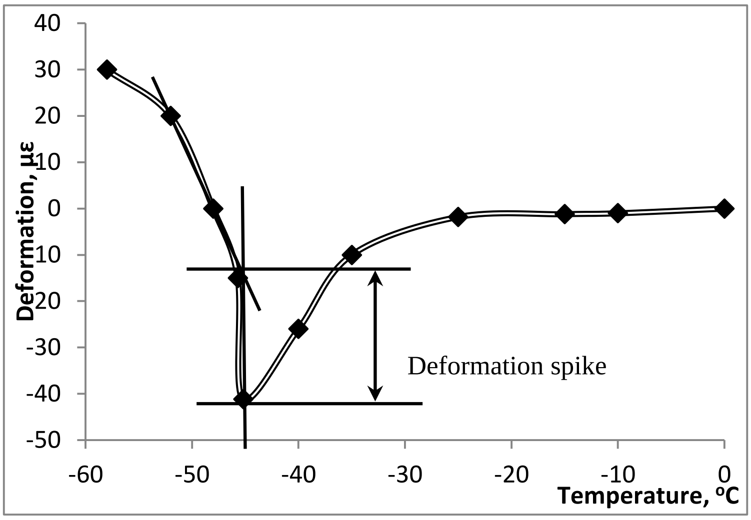


Figure 2 –Temperature dependence of deformation for polymer-modified bitumen PMB 60 in case of using SBS-330L as a modifier
Рис. 2 –Температурная зависимость деформации полимерно-битумного вяжущего ПБВ 60 при использовании в качестве модификатора SBS-330L
Слика 2 –Температурна зависност деформације полимерно-битуменског везива ПМБ 60 када се користи СБС-330Л као модификатор

When the critical temperature reaches minus 44.96°C, there is a sharp spike in deformation and destruction of the binder film, and the stress of its destruction is 5.05 MPa. Therefore, the subsequent decrease in temperature has no significant effect on the deformation properties of the destroyed binder sample, and the PMBs behave as conditionally solid bodies (Mieczkowski et al, 2021; Nebratenko & Nikolaevsky, 2023).

It should be noted that the above figures are given for the case of using linear SBS-polymer as a modifier. In the case of using the brand of branched polymer SBS-330B, the cracking temperature of the binder is higher and the strain jump is noticeably, almost 45%, lower. This correlates well with the previously presented theoretical justifications and practical data on the effectiveness of butadiene styrene thermoplastic elastomers as modifiers of bitumen binder properties (Nebratenko, 2022; Hesp, 2004).

Results

Thus, as a result of the direct determination of the cracking temperature of polymer-bitumen and bitumen binders of various compositions, the influence of the topology of the SBS polymer on the low-temperature properties of a multicomponent road binder was established. Polymers of linear structure, with the same percentage content in a mixture with viscous road petroleum bitumen, provide a lower cracking temperature. For the case of using a radial grade, this indicator is noticeably higher. Traditional bitumen has the lowest absolute value of fragility. This is in good agreement with the theory and practice of road construction (Nebratenko et al, 2022).

Conclusion

The practice of applying the ABCD method in Russian road science and practice does not yet have that broad level of application, which is inherent in the idea of the ABCD device.

And even the seemingly excessive duration of tests (about 4-5 hours), due, as noted earlier, to the reasonable requirements of the national standard GOST R 58400.11-2019, cannot prevent the expansion of its application for direct assessment of one of the most important performance indicators of polymer-bitumen binders - cracking temperature, because if the track or wear in the upper layers are formed gradually over a long period of time, the cracking during cooling develops spontaneously and the growth of the crack opening width increases even more when the temperature of the surface layer of the pavement passes through the zero mark, which in winter conditions in Russia happens with notable regularity.

The conducted studies have shown the practicality of using the ABCD method even in the case of traditional technologies since it gives reliable data on frost resistance and working capacity of binders and, consequently, of coatings based on them, in severe natural and climatic conditions of Russia. A simple hardware design, high-quality domestic software and the safety of the testing process provide this method of assessing the properties of bitumen binders with excellent prospects of development in the near future.

References

Flory, P.J. 1985. Network topology and the theory of rubber elasticity. *British Polymer Journal*, 17(2), pp.96-102. Available at: https://doi.org/10.1002/pi.4980170202.

Gokhman, L.M. 1977. Etude des propriétés rhéologiques des types structuraux de bitume sous déformation statique ou dynamique. In: *Bitumes et enrobes bitumineux: Bull liaison lab ponts chauss*, SPEC V, pp.59-67 [online]. Available at: https://trid.trb.org/view/1058887 [Accessed: 10 April 2023]. ISSN: 0458-5860.

Hesp, S.A.M. 2004. An Improved Low-Temperature Asphalt Binder Specification Method. In*: Development of a Fracture Mechanics-Based Asphalt Binder Test Method for Low Temperature Performance Prediction: Final Report for Highway IDEA Project 84*. Washington, D.C: Transportation Research Board of the National Academies [online]. Available at: https://onlinepubs.trb.org/onlinepubs/archive/studies/idea/finalreports/highway/nchrp84_final_report.pdf [Accessed: 10 April 2023].

Kim, S.-S. 2005. Direct Measurement of Asphalt Binder Thermal Cracking. *Journal of Materials in Civil Engineering*, 17(6), pp.632-639. Available at: https://doi.org/10.1061/(ASCE)0899-1561(2005)17:6(632).

Kim, S.-S. 2007. *Development of an Asphalt Binder Cracking Device: Final Report for Highway IDEA Project 99*. Washington, D.C: Transportation Research Board of the National Academies [online]. Available at: https://onlinepubs.trb.org/onlinepubs/archive/studies/idea/finalreports/highway/NCHRP99Final_Report.pdf [Accessed: 10 April 2023].

Mieczkowski, P., Budziński, B., Słowik, M., Kempa, J. & Sorociak, W. 2021. Experimental Study of Tensile Properties of Styrene-Butadiene-Styrene Modified Asphalt Binders. *Materials,* 14(7), art.number: 1734. Available at: https://doi.org/10.3390/ma14071734.

Nazzal, M.D., Kim, S.-S. & Abbas, A.R. 2014. Evaluation of Winter Pothole Patching Methods. *Rosap* [online]. Available at: https://rosap.ntl.bts.gov/view/dot/27019 [Accessed: 10 April 2023].

Nebratenko, D.Yu. & Nikolaevsky, V.E. 2023*. Metod opredelenija temperatury rastreskivanija bitumnyh vjazhushhih (ABCD): Metodicheskie rekomendacii k laboratornym rabotam.* Moscow: Russian University of Transport (MIIT), in Russian. (In the original: Небратенко, Д.Ю. и Николаевский, В.Е. 2023. *Метод определения температуры растрескивания битумных вяжущих (ABCD): Методические рекомендации к лабораторным работам*. Москва: РУТ (МИИТ).)

Nebratenko, D.Yu. 2022. ABCD – a method for assessing the low-temperature behavior of road binders. *Scientific Journal "Engineering and Construction Bulletin of the Caspian Region"*, 1(39), pp.37-41 [online]. Available at: https://xn--80aai1dk.xn--p1ai/journal/wp-content/uploads/2022/03/isvp_1_39_2022_37-41.pdf (in Russian) [Accessed: 10 April 2023].

Nebratenko, D.Yu., Boksha, M.Yu. & Isakov, A.M. 2022. Influence of SBS polymers of various structure on the properties of semi-blown bitumen binders. *Roads and Bridges - Drogi i Mosty*, 21(1), pp.5-17. Available at: https://doi.org/10.7409/rabdim.022.001.

Petersen, J.C., Robertson, R.E., Branthaver, J.F., Harnsberger, P.M., Duvall, J.J., Kim, S.-S, Anderson, D.A., Christiansen, D. & Bahia, H. 1994. *Binder characterization and evaluation. Volume 1.* Washington, D.C: Strategic Highway Research Program National Research Council [online]. Available at: https://onlinepubs.trb.org/Onlinepubs/shrp/SHRP-A-367.pdf [Accessed: 10 April 2023]. ISBN: 0-309-05809-0.

Plewa, A. 2019 Asphalt mixtures with binders fluidized by addition of vegetable origin oil for applications as flexible anti-crack layers. *Roads and Bridges - Drogi i Mosty*, 18(3), pp.181-192. Available at: https://doi.org/10.7409/rabdim.019.012.

Оценка методом ABCD низкотемпературных свойств смеси битумов и СБС-полимеров различной топологии

Владимир Е. Николаевский[а], *Павел* А. Дужий[б], *Дмитрий* Ю. Небратенко[а,б], **корреспондент**

[а] Российский университет транспорта, кафедра: «Автомобильные дороги, аэродромы, основания и фундаменты», г. Москва, Российская Федерация

[б] МИРЭА-Российский технологический университет, кафедра химии и технологии переработки эластомеров, г. Москва, Российская Федерация

РУБРИКА ГРНТИ: 61.01.81 Измерения, испытания, контроль и управление качеством,
61.51.37 Парафины, битумы и прочие нефтепродукты,
61.61.39 Клеи и герметики,
67.15.00 Технология производства строительных материалов и изделий,
67.15.49 Производство материалов на основе органических вяжущих. Производство асфальтобетона

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение: В связи с изменением климата ученые всего мира, в том числе специалисты дорожно-строительной отрасли, вынуждены принимать в расчет необходимость регулярного контроля низкотемпературных свойств как отдельных строительных материалов, так и свойств многокомпонентных дорожных композитов. Поэтому изучается возможность разработки новых подходов и методов оценки указанных свойств.

Методы: Для указанных целей доктор Kim Sang-Soo предложил новый метод оценки низкотемпературных свойств дорожных вяжущих, который получил название метод ABCD (Asphalt Binder Cracking Device). Использование прибора не требует специальных навыков и знаний, а вспомогательное оборудование широко *доступно в лабораториях дорожно-строительных организаций. Продолжительность испытания не превышает 4-5 часов.*

Результаты: На примере промышленно выпускаемых партий битумов нефтяных дорожных вязких окисленных марки БНД 70/100, с применением методологии ABCD по ГОСТ Р 58.400.11-2019, показана возможность и эффективность регулирования температуры растрескивания битумосодержащих вяжущих путем ввода в состав композиции бутадиен-стирольных термоэластопластов различной топологии.

Выводы: В России, где зимние температуры на подавляющей территории страны опускаются ниже -30^0 С, крайне важна доступность контроля поведения битумных вяжущих и многокомпонентных смесей разного состава (асфальтобетонных смесей). Введен в действие национальный стандарт ГОСТ Р 58400.11-2019 и налажено производство измерительного оборудования. При этом метод ABCD может быть использован как для изучения свойств смесей вяжущих с полимерами различной топологии, так и для выбора товарного вяжущего, соответствующего требованиям конкретного региона эксплуатации автомобильной дороги.

Ключевые слова: температура растрескивания, полимерно-битумные вяжущие, метод ABCD, бутадиен-стирольные термоэластопласты различной топологии.

Процена нискотемпературних својстава смеше битумена и SBS полимера различитих топологија методом ABCD

Владимир Е. Николајевски[а], *Павел* А. Дужиј[б],
Дмитриј Ј. Небратенко[а,б], **аутор за преписку**

[а] Руски универзитет за транспорт, Катедра за ауто-путеве, аеродроме, базе и темеље, Москва, Руска Федерација

[б] МИРЕА - Руски технолошки универзитет, Катедра за хемију и технологије прераде еластомера, Москва, Руска Федерација

ОБЛАСТ: хемијске технологије, хемијска индустрија, грађевинарство, архитектура
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод: У вези са климатским променама, научници широм света, укључујући стручњаке из области изградње путева, приморани су да узму у обзир потребу за редовном контролом нискотемпературних својстава појединих грађевинских материјала и својстава вишекомпонентних композита на њиховој бази. Због тога се проучава могућност развоја нових приступа и метода процене наведених својстава.

Методе: Ким Санг-Су је предложио нову методу за процену својстава везивних материјала за изградњу путева при ниским температурама, коју је назвао ABCD метода (Asphalt Binder Cracking Device). Употреба уређаја не захтева посебне вештине и знања, а помоћна опрема је широко заступљена у лабораторијама компанија за изградњу путева. Испитивање не траје дуже од 4 до 5 сати.

Резултати: На примеру производње индустријских серија нафтних путних вискозних оксидованих битумена марке БНД 70/100, уз примену ABCD методе у складу са стандардима ГОСТ Р 58.400.11-2019, приказана је могућност и ефикасност регулисања температуре пуцања везива у битумену увођењем у његов састав стиренско-бутадиенских термопластичних еластомера различитих топологија.

Закључци: С обзиром на то да зими у већем делу Русије температуре падају испод -30^{0}С, веома је важно омогућити регулисање понашања битуменских везивних и вишекомпонентних смеша различитог састава (асфалтно-бетонске смеше). Утврђен је национални стандард ГОСТ Р 58400.11-2019 и успостављена је производња мерне опреме. ABCD метода се може истовремено користити како за проучавање својстава везивних смеша на бази полимерима различитих топологија, тако и у одабиру везива у комерцијалне сврхе, која морају задовољавати прописе за изградњу ауто-путева конкретног региона у којем ће се користити.

Кључне речи: температура пуцања, полимер-модификовани битумен, ABCD метода, стиренски бутадиен термопластичних еластомера различитих топологија.

Paper received on / Дата получения работы / Датум пријема чланка: 07.05.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 15.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 16.06.2023.

Application of the modeling method to the calculation of the probability of hitting a stationary target during the fire action of a tank squad in defense

Zoran B. Obradović[a], *Branislav* B. Nikolić[b], *Goran* P. Popović[c], *Nikolay* D. Gadzhalov[d], *Krastyu* I. Krastev[e]

[a] University of Defence in Belgrade, Military Academy, Belgrade, Republic of Serbia,
e-mail: obradovicz291@gmail.com,
ORCID iD: https://orcid.org/0009-0006-7078-499X

[b] University of Defence in Belgrade, Military Academy, Belgrade, Republic of Serbia,
e-mail: bane.nnv@gmail.com, **corresponding author**,
ORCID iD: https://orcid.org/0000-0002-9135-8459

[c] Ministry of Internal Affairs of the Republic of Serbia, Police Directorate for the City of Belgrade, Belgrade, Republic of Serbia,
e-mail: popgoranpopovic@gmail.com,
ORCID iD: https://orcid.org/0009-0002-6496-6173

[d] Vasil Levski National Military University, Veliko Tarnovo, Republic of Bulgaria,
e-mail: ndgadzhalov@nvu.bg,
ORCID iD: https://orcid.org/0009-0004-5555-9845

[e] Vasil Levski National Military University, Veliko Tarnovo, Republic of Bulgaria,
e-mail: kikrastev@nvu.bg,
ORCID iD: https://orcid.org/0000-0002-9207-4212

DOI: 10.5937/vojtehg71-44670; https://doi.org/10.5937/vojtehg71-44670

FIELD: firing theory, probability theory, military science
ARTICLE TYPE: original scientific paper

Abstract:

Introduction/purpose: The theory of direct firing of armored units deals with the calculation of the probability of hitting the target depending on the number of projectiles fired, in certain combat circumstances as well as under certain meteorological conditions. Successful performance of the combat task of armored units in defensive actions against stationary targets depends to the greatest extent on the effectiveness of fire of tank weapons. Under the tactical assumptions that define real combat conditions, i.e., that the attacking formation opens fire from small arms and anti-tank weapons, that the defense is organized in a timely manner on maneuvering ground *and in optimal meteorological conditions, and that the tank squad opens fire while stationary, the scientific goal of the research is to determine the probability of hitting and destroying the target as closely as possible depending on the method of determining the distance to the target and the number of projectiles fired.*

Methods: Mainly applying the method of situation modeling in scientific research, the authors try to determine, as precisely as possible, the percentage of the probability of hitting (destroying) a stationary target, with the first, second, or third projectile.

Results: The main scientific contribution of the research would be the determination of various quantitative indicators as significant parameters necessary for a successful design of defense operations of ground army units.

Conclusion: By creating an appropriate model for a specific situation in order to solve a problem (combat task), it is possible to precisely determine the probability of hitting and the probability of destroying the target in relation to the number of projectiles fired, as well as the expected consumption of ammunition.

Key words: firing theory, tank, tank squad, modeling.

Introduction

An attack is a decisive type of combat operations and the most frequently applied type of combat operations of tank units; however, tank units can be used very successfully in defensive operations. Tank units are the basic maneuver formations of the Serbian Armed Forces, which are primarily characterized by armor, maneuver, and firepower. When carrying out defensive operations, armored units most often use direct fire.

Direct fire is achieved by directly aiming at the target and it is a basic way of firing from a firearm characterized by laid trajectories. In principle, it is carried out at distances of one to two cleared ranges while the observation of the target and the hits - correction and assessment of shooting efficiency - is performed from the firing position. During direct fire, there is an increased risk that the weapon opening it will be more easily discovered and exposed to enemy fire (Kokelj & Ranđelović, 2018).

The most significant advantages of direct compared to indirect fire are: simpler, faster, and more accurate determination of firing elements; faster and more accurate aiming of the weapon at the target and opening fire; simpler, faster, and more accurate execution of correction; high hit probability within the limits of the cleared range, as well as greater speed, efficiency and economy of task execution.

One of the most important elements in the process of developing firepower of armored units was the modernization of sighting and observation equipment and fire control systems, which is a direct prerequisite for the successful exploitation of weapons. Also, due to the development of armored combat vehicles, well-trained personnel are necessary so that the technique can be used as correctly and efficiently as possible, and this was best proven in the Arab-Israeli war when Israel won victories over much more powerful Arab countries.

The method of modeling is a research procedure that generates a sign system, a model, that can replace a real phenomenon and by which we can, experimentally or by simulation, investigate and transfer the obtained data from the model to the real phenomenon (Bešić, 2019). Considering all the above mantioned, the method of modeling is very applicable in various scientific fields (Nikolic & Kostic-Stankovic, 2022; Stojković et al, 2022; Janković, 2004; Varecha & Majchút, 2019; Drakulić et al, 2023; Projović et al, 2014), as well as in firing theory and warfare in general. The basic characteristic of the modeling method is the close unity of theory and scientific practice.

Model of the situation

The modeled situation of the M-84 tank conflict against artillery weapon was carried out under the following assumptions (Janković, & Nikolić, 2009):

- Tank is well protected and camouflaged in a squad defense area;
- Tank and artillery weapon have observation and aiming devices which are used for observation and fire control;
- Tank and artillery weapon can hit the enemy with probabilities as a function of distance. Average weapon preparation times, projectile flight speeds to the target, and ammunition combat kit sizes are not taken into account;
- Conflict begins when the tank crew spots the enemy using their observation-aiming device;
- Artillery gun return fire is not considered until the end of the conflict; and
- Conflict ends when the third projectile is fired by the tank crew.

An M-84 tank squad occupies the defense area designated by the platoon commander. The commander of the tank squad opens fire, with the fire control system turned on, from the artillery weapon observed at landmark number 1 (distance 1800 meters), left 0-30, further 100 meters (Fig. 1). Ammunition produced in the Republic of Serbia (high explosive shell -TFP M86) is fired by the decision of the tank commander based on the characteristics of the target.

The dimensions of the target, which is provided by the model (artillery weapon), are: width: 1.8m and height: 1.75m.

The following parameters are necessary to be determined: initial elements for firing, the probability of hitting and destroying the target with three projectiles (given the well-camouflaged firing position, the enemy is not expected to detect the tank before the third projectile is fired), and the mathematical expectation of ammunition consumption.

The already known data:

– average number of hits to destroy the target $\omega = 1.1$ (Kokelj & Ranđelović, 2016);
– target shape coefficient $k_f = 0.81$ ($\sqrt{k_f} = 0.9$) (Kokelj & Ranđelović, 2016);
– radius of the explosion cloud r=10m (Medija centar „Odbrana“, 2017).

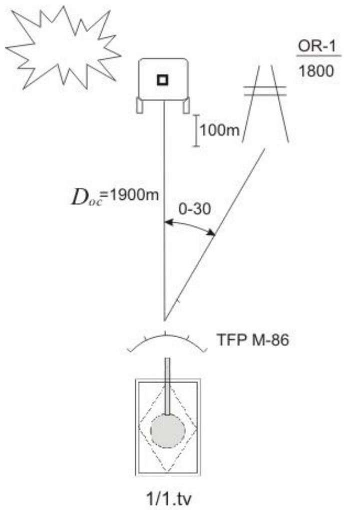


Figure 1 – Sketch of the modeled situation
Рис. 1 – Эскиз моделируемой ситуации
Слика 1 – Скица моделоване ситуације

Firing while not on the move is the most effective way of firing. It enables the highest speed of firing and the probability of hitting the target because all actions of preparation and execution of shooting are done on the spot. The weakness of this firing method is that only fire is used from the combat characteristics of the armored fighting vehicle. Firing from a stationary tank is mainly used in: defense, ambush, repelling counterattacks, and when shooting at long distances, but firing from a halt is possible and very applicable when performing offensive actions.

The firing theory considers this shooting as basic:

- because the distance and direction to the target do not change, and
- the data obtained when considering this firing mode is used to explain the other firing modes.

Firing preparation

It aims to obtain the maximum probability of hitting the target with the first projectile. The firing preparation includes:

- preliminary preparation and
- immediate preparation.

Preliminary preparation is done before the combat and includes:

- preparation of weapons and aiming devices,
- ammunition preparation,
- determination of ballistic and meteorological conditions,
- terrain study, selection of landmarks and determination of the distance to individual lines, points and local facilities, and
- preparation of the crew.

Immediate preparation includes:

- the choice and arrangement of the firing position,
- observation of the battlefield and detection of targets,
- determining the distance, direction and speed of the target,
- target display,
- choice of target, weapon, projectile and igniter,
- choice of the firing mode,
- determining the direction and speed of own combat vehicle movement,
- determination and adjustments due to the deviation of firing conditions from the firing tables conditions,
- determination of the initial elements, and
- issuing the fire command.

Even with the most careful fire preparation, random errors occur. These errors are subject to the normal law of errors and are characterized by certain mean probable errors affecting the flight of the projectile in height, distance and direction.

Firing preparation errors include:

- errors of technical preparation,

- errors in determining the distance to the target,
- rounding errors,
- meteorological preparation errors,
- ballistic preparation errors, and
- errors due to tank leaning.

• Errors of technical preparation (E_{tp}) - primarily include errors in checking and adjusting aiming devices and weapons, as well as tolerance errors in the manufacture of aiming devices (NS) and the application of scales. Technical preparation errors affect the distance error E_{xtp}, direction E_{ztp}, and height E_{ytp}.

Table 1 – Technical preparation errors (Savić, 1996, p.103)
Таблица 1 – Ошибки технической подготовки (Savić, 1996, p.103)
Табела 1 – Грешке техничке припреме (Savić, 1996. p.103)

TYPES OF ERRORS	MEAN PROBABLE ERRORS		
	By direction, E_{ztp}	By distance, E_{xtp}	By height, E_{ytp}
Errors in checking weapons and aiming devices (milliradians)	0.3	$0.3 \cdot \Delta x$	0.3

• Errors in determining the distance to the target (E_d)

Determining the distance to the target must be done quickly and as accurately as possible. Errors in determining the distance are subject to the normal law of errors and are characterized by the mean probable error E_d, which depends on the means and the method of determining the distance to the target, and whose values are determined empirically and experimentally.

Table 2 – Errors in determining the distance to the target (Savić, 1996, p.103)
Таблица 2 – Ошибки определения дистанции до цели (Savić, 1996, p.103)
Табела 2 – Грешке у одређивању даљине до циља (Savić, 1996, p.103)

MEANS AND METHODS OF DETERMINING THE DISTANCE TO THE TARGET	MEAN PROBABLE ERROR E_d
By evaluating the output from the tank, day and night	15-20%
By rating from the outside of the tank, day and night	10-15%
Using the scales of the aiming device	10%
According to the mean angle of the target	10%
In relation to a landmark whose distance was measured with a rangefinder	4-6%
According to the map or by cutting with dome protractors	4%
With a range finder	2-4%
With a tape measure	0.2%
Laser rangefinder	2.5m ($\pm$5m)

- Rounding errors (E_{xzkr})

The rounding of elements is subject to the law of equal probability whose parameters are: $2l = \Delta x$ milliradians, and since E=0.39, it follows that

$E_{xzkr} = 0.2 \cdot \Delta x$ (milliradians).

- Errors of meteorological preparation (E_{xm},E_{zm})

The size of the meteorological preparation errors is affected by the direction of crosswind and by the distance of longitudinal wind, barometric air pressure and air temperature, so the mean probable errors are:

– along the direction: E_{zm} =0.6 milliradians, and
– by distance: E_{xm} =0.6%.

- Ballistic preparation errors (E_{xb},E_{zb})

The magnitude of the ballistic preparation error is affected by the derivation in direction and by distance: the initial velocity V_0, the temperature of the powder charge, and the weight of the projectile for one weight mark.

The mean probable errors are:

– by direction: E_{zb} =0.25 milliradians, and
– by distance: E_{xb} =0.7%.

- Tank leaning errors (E_{znt})

In terms of height and distance, the errors are negligible, and in terms of direction, they amount to:

E_{znt} =0.2 milliradians.

Summarized mean errors in target preparation

Errors by distance:

$$E_{xp} = \sqrt{E_{xtp}^2 + E_d^2 + E_{xm}^2 + E_{xb}^2 + E_{xzkr}^2} \qquad (1)$$

Errors by direction:

$$E_{zp} = \sqrt{E_{ztp}^2 + E_{zm}^2 + E_{zb}^2 + E_{znt}^2} \qquad (2)$$

If we calculate the values of the total error by distance E_{xp} and by direction E_{zp}, for different distances and different degrees of distance determination accuracy, we will get the following values:

Table 3 – Summarized errors by distance (Savić, 1996, p.105)
Таблица 3 – Суммарные ошибки по расстоянию (Savić, 1996, p.105)
Табела 3 – Сумарне грешке по даљини (Savić, 1996, p.105)

Shooting distance in meters (m)	Partial values of SVG in the preparation of shooting in meters							Summarized E_{xp} at E_d in %D		
	E_{xtp}	E_{xb}	E_{xm}	E_{xzkr}	determination of D in %E_d			5	10	15
					5	10	15	m/%	m/%	m/%
1000	45	7	6	30.2	50	100	150	74.31 7.4%	114.11 11.41%	159.75 15.75%
1500	43	10	9	28.4	75	150	225	91.98 6.1%	159 11%	231 15.5%
2000	40.5	14	12	27	100	200	300	112.73 5.6%	206 10.3%	304.48 15%

E_{zp} - the size of the mean probable error by direction and firing preparation is always 0.74 milliradians and is calculated in meters.

$$E_{zp}\,(\text{meters}) = 0.74 \cdot 0.001\, D \qquad (3)$$

Analyzing the table, we can conclude that the size of errors in preparation, and the preparation and accuracy of long-range shooting, depends mainly on the accuracy of determining the distance to the target and the accuracy of technical preparation, to a lesser extent on rounding errors, while the errors caused by meteorological and ballistic preparation are almost negligible.

Assessment of efficiency of firing at stationary targets

a) the distance to the target was measured with a laser rangefinder

The initial elements:

- Starting distance: 1880m (determined with a laser rangefinder),
- Sight mark: the tip of the main arrow, and
- Aiming point: the center of the target.

The data from the firing tables for the 125mm HE M86 round (Medija centar „Odbrana“, 2017, p.56):

Table 4 – Data from the firing tables for the 125mm gun
Таблица 4 – Данные из таблицы стрельбы для 125-мм орудия
Табела 4 – Подаци из таблице гађања за топ 125 мм

Parameters	Value	Units
D_{Mr}	1900	meter
V_d	21.69	meter
V_p	0.4	meter
V_c	0.41	meter
θ_c	18	milliradians

First projectile

- Preparation error by direction:

$$E_{zp} = \sqrt{E_{zt}^2 + E_{zb}^2 + E_{zm}^2 + E_{znt}^2} = 0.74\text{milliradians}$$

E_{zp} (meters)=0.74·0.001D_g =1.3912

- Remote preparation error:

$$E_{xp} = \sqrt{E_{xt}^2 + E_d^2 + E_{xm}^2 + E_{xb}^2 + E_{xzkr}^2}$$

E_{xp} =5 m (mean error of the laser rangefinder)

- Total errors for the 1st firing:

– by direction:

$$V_{pp_1} = \sqrt{E_{zp}^2 + V_p^2} = 1.447\,\text{m} \tag{4}$$

– by distance:

$$V_{dp_1} = \sqrt{E_{xp}^2 + V_d^2} = 22.26\,\text{m} \tag{5}$$

- Hit probability with the 1st projectile:

$$P_{c_1} = P_{p_1} \cdot P_{d_1} = F \cdot \left(\frac{m \cdot \sqrt{k_f}}{V_{pp1}} \right) \cdot F \cdot \left(\frac{l \cdot \sqrt{k_f}}{V_{dp1}} \right) \tag{6}$$

2m=1.8m $\Rightarrow$ m=0.9m

$$2l = \frac{H_c \cdot 1000}{\theta_c} = 97.22\text{m} \tag{7}$$

$$P_{c_1} = 0.2402$$

$$P_{c_1} = 24.02\%$$

- For the second and the third projectile, the distance is only checked again with the laser rangefinder, which implies that the hit probabilities are approximately the same as for the first projectile.

➢Precise probability of destroying the target with:

– 1st projectile:

$$W_1 = \frac{Pc_1}{\omega} = 0.2184 \tag{8}$$

– 2nd projectile:

$$W_2 = \frac{Pc_2}{\omega} \cdot \left(1 - \frac{Pc_1}{\omega}\right) = 0.1707 \quad (9)$$

– 3rd projectile:

$$W_3 = \frac{P_{c_3}}{\omega} \cdot \left(1 - \frac{P_{c_2}}{\omega}\right) \cdot \left(1 - \frac{P_{c_1}}{\omega}\right) = 0.1334 \quad (10)$$

➢Full target destruction probability:

$$W_c = W_1 + W_2 + W_3 \quad (11)$$

$$W_c = 0.5225$$

$$W_c = 52.25\%$$

➢Mathematical expectation of ammunition consumption (Tomović, 1998):

MO_{Npr}= $1W_1+2W_2+3W_3+(3+1.5)W_{zst}$ (12)

W_{zst}= $1-W_c$=0.4775 (13)

MO_{Npr}= 3.11

MO_{Npr}= 4 projectiles

b) *fire control system on - cannot enter range to the target manually, a faulty laser rangefinder. The distance to the target determined by eye, during daylight from a combat vehicle.*

The initial elements:

– Starting distance :1900m,
– Sight mark: the 3rd lower auxiliary dash (table angle 0-14), and
– Aiming point: top of the target.

The data from the firing tables for the 125mm HE M86 round (Medija centar „Odbrana“, 2017, p.56):

Table 5 – Data from the firing tables for the 125mm gun
Таблица 5 – Данные из таблицы стрельбы для 125-мм орудия
Табела 5 – Подаци из таблице гађања за топ 125 мм

Parameters	Value	Units
D_{Mr}	1900	meter
V_d	21.69	meter
V_p	0.4	meter
V_c	0.41	meter
θ_c	18	milliradians
Δx	105.55	meter

E_{xzkr} = 80 meters (14)

First projectile

- Preparation errors by direction:

$$E_{zp} = \sqrt{E_{zut}^2 + E_{zb}^2 + E_{zm}^2 + E_{znt}^2} = 0.74 \text{ milliradians}$$

E_{zp} (meters)=0.74 · 0.001· D_g= 1.406

- Preparation errors by distance:

$$E_{xp} = \sqrt{E_{xt}^2 + E_d^2 + E_{xm}^2 + E_{xb}^2 + E_{xzkr}^2}$$
$$E_{xp} = 209.31\text{m} \tag{15}$$

- Total errors for the 1st firing:

– by direction:

$$V_{pp_1} = \sqrt{E_{zp}^2 + V_p^2} = 1.462\text{m} \tag{16}$$

– by distance:

$$V_{dp_1} = \sqrt{E_{xp}^2 + V_d^2} = 210.43\text{m} \tag{17}$$

- Hit probability with the 1st projectile:

$$P_{c_1} = P_{p_1} \cdot P_{d_1} = F\left(\frac{m \cdot \sqrt{k_f}}{V_{pp_1}}\right) \cdot F\left(\frac{l \cdot \sqrt{k_f}}{V_{dp_1}}\right) = 0.0326$$
$$P_{c_1} = 3.26\% \tag{18}$$

Second projectile

$$\frac{2l}{V_d} = 4.48 V_d$$
$$\frac{E_{xp}}{V_d} = 9.65 V_d \tag{19}$$

k_2 =0.5135; k_3 =0.3235 (20)

- Total errors for the 2nd firing:

– by direction:

$$V_{pp_2} = \sqrt{(0.1 \cdot r)^2 + 2 \cdot V_p{}^2} = 1.15\,m \tag{21}$$

– by distance:

$$V_{dp_2} = \sqrt{(k_2 \cdot E_{xp})^2 + V_d{}^2} = 109.65\,m \tag{22}$$

- Hit probability for the 2nd projectile:

$$P_{c_2} = P_{p_2} \cdot P_{d_2} = F\left(\frac{m \cdot \sqrt{k_f}}{V_{pp_2}}\right) \cdot F\left(\frac{l \cdot \sqrt{k_f}}{V_{dp_2}}\right) \tag{23}$$

$$P_{c_2} = 7.72\%$$

Third projectile

- Total errors for the 3rd firing:

– by direction:

$$V_{pp_2} \approx V_{pp_3} = 1.15\text{m} \tag{24}$$

– by distance:

$$V_{dp_3} = \sqrt{(k_3 \cdot E_{xp})^2 + V_d{}^2} = 71.1\text{m} \tag{25}$$

- Hit probability with the 3rd projectile:

$$P_{c_3} = P_{p_3} \cdot P_{d_3} = F\left(\frac{m \cdot \sqrt{k_f}}{V_{pp_3}}\right) \cdot F\left(\frac{l \cdot \sqrt{k_f}}{V_{dp_3}}\right) = 0.1177 \tag{26}$$

$$P_{c_3} = 11.77\%$$

➢Target destruction probability as mentioned in equations (8-11):
W_c= 19.42 %

➢Mathematical expectation of ammunition consumption:

MO_{Npr}= $1W_1+2W_2+3W_3+(3+1.5)W_{zst}$ (27)
W_{zst}= $1-W_c$=0.8058 (28)
MO_{Npr}= 4.08
MO_{Npr}= 5 projectiles

Analysis

It should be taken into account that the target hit and destruction probability is calculated for a direct hit of the projectile on the target. With each hit of a projectile within a diameter of 14 meters from the target (surface of strong impact – 80 percent of the manpower destroyed), it is considered destroyed (Medija centar „Odbrana“, 2017).

Table 6 – Comparative analysis of firing at a stationary target from a stationary tank
Таблица 6 – Сравнительный анализ стрельбы по неподвижной цели
Табела 6 – Упоредна анализа гађања са места непокретног циља

Method of determining the distance to the target		with a laser rangefinder	without a laser rangefinder
Shooting distance (meters)		1880	
Hit probability (%)	With the 1st projectile	24.02	3.26
	With the 2nd projectile	24.02	7.72
	With the 3rd projectile	24.02	11.77
Total probability of target destruction		52.25	19.42
Mathematical expectation of ammunition consumption (projectiles)		4	5

A comparative analysis of the obtained results leads to the conclusion that the probability of destroying the target with three projectiles is 2.7 times higher when using a laser rangefinder to obtain the distance to the target. The probability of destruction of the target when determining the distance to the target by eye, during daylight from a combat vehicle and due to the impossibility of entering the distance manually into the computer, is 19.42%.

The probability of destroying the target is small because the error of preparation for distance shooting (E_{xp}) is much higher when the laser rangefinder is defective and, in this case, it is 209.31 meters, while when determining the distance with a laser rangefinder it is 5 meters.

The biggest impact on the distance firing preparation error (E_{xp}) is the error in determining the distance to the target (E_d) and the rounding error (E_{xzkr}) due to the absence of a target mark for the given firing distance, so the marksman is forced to take approximate values.

The importance of a correct laser rangefinder is also reflected in the consumption of ammunition, which is directly related to the probability of destroying the target (Janković & Nikolić, 2009).

The low values of the probability of destruction of the target, shown in Table 6, are explained, in addition to the reasons mentioned in the analysis of the results, by the small dimensions of the target, which at a given distance is considered a target of small dimensions.

Conclusion

By applying the method of modeling to calculate the probability of hitting a stationary target, during the fire action of a tank squad in defense, we can provide relatively precise numerical indicators expressed by a certain mathematical probability. In the paper, by applying exact mathematical calculations, the probabilities of hitting (destroying) the target are obtained, depending on the number of fired projectiles, while their comparative analysis provides an additional quality of scientific research.

The scientific paper specifically points to some possibilities of applying the method of modeling, which is inherent in the research of social phenomena, in a specific case applied to the firing theory as one of the scientific sub-disciplines of the art of war.

This way of modeling combat operations of armored, as well as other ground units to which tanks have been added, is a research procedure by which a sign system, a model, is generated in order to replace a real phenomenon and by means of which we can experimentally or by simulation research and transfer the obtained data from the model to a real combat situation, i.e., solve a specific combat task. The method provides the possibility of a better prediction of the development of the operation and, therefore, the possibility of a better assessment, which is the basis of quality planning of combat operations of tank units.

We can consider it a special benefit that a similar model, almost in its original form, can be applied to other real problems and situations that arise when designing combat operations of armored units.

The assumptions of the above-discussed model and calculations are limited by the initial assumption and represent the basis for expanding the research in the direction of determining the possibility of survival of the tank crew on the battlefield in more complex conditions than those described in this paper.

References

Bešić, M. 2019. *Metodologija društvenih nauka*. Belgrade: Akademska knjiga (in Serbian). ISBN: 978-86-6263-280-7.

Drakulić, M.M., Đurić, A.S., Ponorac, L.M., Benmeddah, A.B. & Perić, S.R. 2023. Modeling and simulation of hydraulic buffering valve for power-shift transmission. *Vojnotehnički glasnik/Military Technical Courier*, 71(2), pp.417-438. Available at: https://doi.org/10.5937/vojtehg71-43175.

Janković, R. 2004. Computer simulation of ammunition consumption until the first hit in a sudden two-tank conflict. *Vojnotehnički glasnik/Military Technical Courier*, 52(3-4), pp.321-330 (in Serbian). Available at: https://doi.org/10.5937/vojtehg0404321J.

Janković, R. & Nikolić, N. 2009. *Primene simulacija u proučavanju fizionomije savremenog rata, monografija*. Belgrade: University of Defence, Strategic Research Institute (in Serbian). ISBN: 978-86-81121-05-4.

Kokelj, T. & Ranđelović, A. 2016. *Zbirka rešenih zadataka iz pravila gađanja naoružanjem pešadije*. Belgrade: Medija centar „Odbrana“ (in Serbian). ISBN: 978-86-335-0502-4.

Kokelj, T. & Ranđelović, A. 2018. *Teorija gađanja, prvo izdanje*. Belgrade: S4 Glosec Globalna bezbednost (in Serbian). ISBN: 978-86-80692-03-6.

-Medija centar „Odbrana“. 2017. *Tablice gađanja za tenkovski top 125mm D-81(2A46), tenkovski mitraljez 7,62mm PKT(m86) i KNO 12,7 mm za tenk M-84*. Belgrade: Medija centar „Odbrana“ (in Serbian).

Nikolic, D. & Kostic-Stankovic, M. 2022. Improving the Economic Sustainability of the Fashion Industry: A Conceptual Model Proposal. *Sustainability,* 14(8), art.number:4726. Available at: https://doi.org/10.3390/su14084726.

Projović, D., Petrović, A. & Jovanović, M. 2014. Cost optimization of artillery fire support using the global positioning system. *Vojno delo*, 66(4), pp.101-110 (in Serbian). Available at: https://doi.org/10.5937/vojdelo1404101p.

Savić, S. 1996. *Teorija gađanja naoružanjem oklopnih jedinica*. Belgrade: Centar vojnih škola Vojske Jugoslavije, Vojnotehnička akademija, katedra naoružanja (in Serbian).

Stojković, P., Kovačević, M. & Vladisavljević, R. 2022. The problem of synthesizing financial statements in reorganization during the bankruptcy process. *Pravo - teorija i praksa*, 39(3), pp.99-112. Available at: https://doi.org/10.5937/ptp2203099S.

Tomović, S. 1998. Application of the experiment statistic simulation method. *Vojnotehnički glasnik/Military Technical Courier,* 46(4), pp.460-466 (in Serbian). Available at: https://doi.org/10.5937/VojTehG9804460T.

Varecha, J. & Majchút, I. 2019. Modelling of Artillery Fire and Simulation of its Efficiency. In: *International conference KNOWLEDGE-BASED ORGANIZATION*, 25(3), pp.174-180. Available at: https://doi.org/10.1515/kbo-2019-0134.

Применение метода моделирования при расчете вероятности огневого поражения неподвижной цели танковым подразделением в обороне

Зоран Б. Обрадович[а] , *Бранислав* Б. Николич[а], **корреспондент**,
Горан П. Попович[б], *Николай* Д. Гаджалов[в], *Крастью* И. Крастев[в]

[а] Университет обороны в г. Белград, Военная академия,
г. Белград, Республика Сербия

[б] Министерство внутренних дел Республики Сербия,
Полицейское управление города Белграда,
г. Белград, Республика Сербия

[в] Национальный военный университет имени Василя Левского,
г. Велико Тырново, Республика Болгария

РУБРИКА ГРНТИ: 78.21.47 Баллистика. Теория стрельбы,
27.43.00 Теория вероятностей и математическая статистика,
27.43.51 Применение теоретико-вероятностных и статистических методов

Резюме:

Введение/цель: Теория стрельбы прямой наводкой танковых подразделений основана на расчете вероятности поражения цели, которая зависит от количества выпущенных снарядов в определенных боевых, а также метеорологических условиях. Успешное выполнение боевой задачи танковыми подразделениями при выполнении боевых действий против неподвижной цели в наибольшей степени зависит от эффективности огня танкового вооружения. Исходя из тактической гипотезы, определяющей реальные боевые условия, которая предполагает, что атакующее подразделение открывает огонь из стрелкового оружия и противотанкового вооружения, при этом оборона хорошо и своевременно организована на маневренной местности и в оптимальных метеорологических условиях, а также что танковое подразделение достигает эффективности огня с места, научная цель данного исследования состоит в определении наиболее точной вероятности поражения и уничтожения цели, в зависимости от метода определения расстояния до цели и количества выпущенных снарядов.

Методы: Преимущественно применяя метод ситуационного моделирования в научном исследовании, авторы стараются как можно точнее определить процент вероятности поражения (уничтожения) неподвижной цели первым, вторым или третьим снарядом.

Результаты: Основным научным вкладом данного исследования является определение различных количественных показателей *и значимых параметров, необходимых для успешного планирования оборонительных операций, совершаемых подразделениями сухопутных войск.*

Выводы: Благодаря созданию соответствующей модели для конкретной ситуации с целью решения проблемы (боевой задачи), можно с точностью определить вероятность поражения и уничтожения цели в зависимости от количества выпущенных снарядов, а также сделать точный прогноз расхода боеприпасов.

Ключевые слова: теория стрельбы, танк, танковые войска, моделирование.

Примена методе моделовања на израчунавање вероватноће поготка непокретног циља приликом ватреног дејства тенковског одељења у одбрани

Зоран Б. Обрадовић[а], *Бранислав* Б. Николић[а], **аутор за преписку**, *Горан* П. Поповић[б], *Николај* Д. Гаџалов[в], *Крастиу* И. Крастев[в]

[а] Универзитет одбране у Београду, Војна академија, Београд, Република Србија

[б] Министарство унутрашњих послова Републике Србије, Управа полиције за град Београд, Београд, Република Србија

[в] Национални војни универзитет „Васил Левски", Велико Трново, Република Бугарска

ОБЛАСТ: теорија гађања, теорија вероватноће, војне науке
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Теорија непосредног гађања оклопних јединица бави се израчунавањем вероватноће поготка циља, у зависности од броја испаљених пројектила, у одређеним борбеним околностима, као и под одређеним метеоролошким условима. Успешност извршења борбеног задатка оклопних јединица у извођењу одбрамбеног дејства на непокретни циљ у највећој мери зависи од ефикасности ватреног дејства тенковског оруђа. Тактичком претпоставком дефинисани су реални борбени услови – да нападачка формација наступа отварајући ватру из стрељачког и противоклопног наоружања, да је одбрана организована правовремено, на маневарском земљишту и у оптималним метеоролошким условима, као и да тенковско одељење остварује ватрено дејство са места. Циљ истраживања јесте да се што приближније одреди *вероватноћа погодка и уништења циља, у зависности од начина одређивања даљине до циља и броја испаљених пројектила.*

Методе: Тежишном применом методе ситуационог моделовања у научном истраживању, настојано је да се што прецизније одреди проценат вероватноће поготка (уништења) непокретног циља – првим, другим, односно трећим пројектилом.

Резултати: Главни научни допринос истраживања представља одређивање различитих квантитативних показатеља као значајних параметара неопходних ради успешног пројектовања одбрамбених операција јединица копнене војске.

Закључак: Креирањем одговарајућег модела за одређену ситуацију, ради решавања проблема (борбеног задатка), могуће је прецизно одредити вероватноћу погађања и уништења циља у односу на број испаљених пројектила, као и очекивани утрошак муниције.

Кључне речи: теорија гађања, тенк, тенковско одељење, моделовање.

Paper received on / Дата получения работы / Датум пријема чланка: 24.12.2022.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 12.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 14.06.2023.

ПРЕГЛЕДНИ РАДОВИ

ОБЗОРНЫЕ СТАТЬИ

REVIEW PAPERS

The Casimir effect

Nicola Fabiano

University of Belgrade, "Vinča" Institute of Nuclear Sciences - National Institute of the Republic of Serbia, Belgrade, Republic of Serbia,
e-mail: nicola.fabiano@gmail.com,
ORCID iD: https://orcid.org/0000-0003-1645-2071

DOI: 10.5937/vojtehg71-41282;https://doi.org/10.5937/vojtehg71-41282

FIELD: mathematics
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose: The quantization of the electromagnetic field gives rise to quantum fluctuations which in turn produce a force on macroscopic boundaries. This phenomenon is called the Casimir effect.

Method: The second quantization of the electromagnetic field is employed. The Zeta function regularization technique has been applied.

Results: Because of the electromagnetic field quantization, a force on macroscopic boundaries is observed.

Conclusions: Vacuum fluctuations due to quantum effects give macroscopic results.

Key words: quantum electrodynamics, quantization, vacuum energy, Casimir effect.

The Casimir effect

We are going to consider an effect arising from the electromagnetic field quantization. Casimir first observed that, because of quantum fluctuations of the electromagnetic field, between two neutral parallel conducting plates separated by a distance d and located in a vacuum, there is a force which is attractive in this particular geometry. This is known as the *Casimir effect* (Casimir, 1948; Casimir & Polder, 1948; Casimir, 1953). Only transverse modes will contribute to the energy, and, assuming the plates are perpendicular to the direction x of propagation, that component will have nodes on the planes and will take discrete values

$$\mathbf{k} = (k_x = n\pi/d, k_y, k_z),\ n = 1, 2, \ldots ; \mathbf{n} = \left(\frac{d}{\pi}\right)\mathbf{k}\ . \tag{1}$$

The zero point energy of this configuration is given by

$$E = \sum_{n=1}^{+\infty} \frac{1}{2}\hbar\omega_n = \sum_{\mathbf{n}} \frac{1}{2}\hbar c|\mathbf{k_n}| \tag{2}$$

For the sake of simplicity, we will limit ourselves to a $1+1$ dimensional space, i.e. $1D$, in order not to deal with k_y and k_z, the components of the electromagnetic wave vector. Therefore, the modes are given by $\sin(n\pi x/d)$, where $n = 1, 2, \ldots$ and the corresponding energy is $\omega_n = \pi n/d$. Plugging all this back into eq. (2), for the vacuum energy in one spatial dimension, we obtain the expression

$$E(d) = \frac{\pi}{2}\frac{\hbar c}{d}\sum_{n=1}^{+\infty} n\ . \tag{3}$$

Of course the term $\sum_{n=1}^{+\infty} n$ is a source of trouble being divergent. In order to solve this problem, let us introduce the generating function

$$\sum_{n=1}^{+\infty} e^{-an} \tag{4}$$

for $a > 0$, this series is, of course, convergent to

$$\frac{1}{1-e^{-a}} \tag{5}$$

and has the property that

$$-\frac{d}{da}\sum_{n=1}^{+\infty} e^{-an} = \sum_{n=1}^{+\infty} ne^{-an} \tag{6}$$

so that in the limit $a \to 0$ we recover the sum of eq. (3). Besides its mathematical properties in the series, the parameter a plays a role as a cutoff for frequencies with a wavenumber n larger than $1/a$. We will isolate the source of divergence for $a \to 0$, obtaining a finite value for the zero point energy.

Fabiano, N., The Casimir effect, pp.740–747

Taking the derivative of eq. (5) with respect to a, we obtain

$$\sum_{n=1}^{+\infty} n e^{-an} = -\frac{d}{da}\left(\frac{1}{1-e^{-a}}\right) = \frac{1}{e^a + e^{-a} - 2}. \tag{7}$$

Expanding (7) with Taylor for small a (i.e. taking into account higher frequencies), we have

$$\frac{1}{a^2}\frac{1}{1+\frac{1}{12}a^2+\mathcal{O}(a^4)} = \frac{1}{a^2}\left(1 - \frac{1}{12}a^2 + \mathcal{O}(a^4)\right) = \frac{1}{a^2} - \frac{1}{12} + \mathcal{O}(a^2) \tag{8}$$

The expression for the zero point energy (3) becomes

$$E(d) = \frac{\pi}{2}\frac{\hbar c}{d}\left(\frac{1}{a^2} - \frac{1}{12} + \mathcal{O}(a^2)\right) \tag{9}$$

and we observe that the divergent part goes like $1/a^2$, while all other remaining terms are regular in the limit $a \to 0$. As it stands, E does not have a definite value. Remembering that the energy is defined up to a constant, we should regularize it by subtracting a suitable “counterterm” $E_C(d)$ that will eventually furnish us with a finite value for E. For a discussion of the counterterms in Quantum Electrodynamics, consult (Fabiano, 2021), and for the various regularization techniques in Quantum Field Theory, see (Fabiano, 2022). Defining the counterterm in the following manner

$$E_C(d) = \frac{\pi}{2}\frac{\hbar c}{d}\frac{1}{a^2} \tag{10}$$

that is, the sole divergent part of (9) and subtracting it to $E(d)$, we end up with a perfectly regularized energy value for $a = 0$:

$$E_R(d) = E(d) - E_C(d) = \frac{\pi}{2}\frac{\hbar c}{d}\left(-\frac{1}{12} + \mathcal{O}(a^2)\right) \tag{11}$$

What experimentalists do measure in the Casimir effect is the force among plates, that is $F = -\partial E/\partial d$ and, of course, this value does not blow up. The complete expression for the (attractive) force between two plates is

$$F = -\frac{\partial E(d)}{\partial d} = -\frac{\pi}{2}\frac{\hbar c}{d^2}\left(\frac{1}{a^2} - \frac{1}{12} + \mathcal{O}(a^2)\right) \tag{12}$$

whose regular part is just given by $F_R = -\partial E_R(d)/\partial d$:

$$F_R = \frac{\pi}{24}\frac{\hbar c}{d^2} \tag{13}$$

as all other terms vanish in the limit $a \to 0$. This is the finite result for the Casimir force in $1D$.

To summarize, while computing the zero point energy, we stumble upon the divergent term $\sum_n n$. In order to regularize its behavior, we introduce a parameter a that goes to zero thus discovering the pole $1/a^2$ and other regular terms.Then we subtract a suitably "infinite" term that cancels the divergent part and retain the finite value for $a = 0$.

For the sake of completeness, a more exhaustive expansion of (7) in powers of a is given by

$$\frac{1}{a^2} - \frac{1}{12} + \frac{a^2}{240} - \frac{a^4}{6048} + \frac{a^6}{172800} - \frac{a^8}{5322240} + \frac{691\,a^{10}}{118879488000} + \mathcal{O}(a^{12}), \tag{14}$$

where the coefficients are related to Bernoulli numbers.

An alternative approach to the generating function, of course completely equivalent, is the well–known regularization via the Riemann zeta function defined for $\Re(s) > 1$

$$\zeta(s) = \sum_{n=1}^{+\infty} n^{-s} \tag{15}$$

and extended on the whole complex plane to a meromorphic function, i.e. that is holomorphic everywhere except for a simple pole at $s = 1$ with residue 1, see for instance (Fabiano, 2020). It is possible to show that

$$\zeta(-1) = -\frac{1}{12}\,. \tag{16}$$

Three dimensional case

In spatial $3D$, that is $3+1$ dimensions, we restore the other two components k_y and k_z of the wave vector which of course are not subject to boundary conditions due to the presence of the plates. The frequency is written as

$$\omega_n = c\sqrt{\frac{n^2\pi^2}{d^2} + k_y^2 + k_z^2} \tag{17}$$

giving the expression for the energy

$$E(d) = \frac{\hbar}{2} \cdot 2A \int \frac{\mathrm{d}k_y \mathrm{d}k_z}{(2\pi)^2} \sum_{n=1}^{+\infty} \omega_n \tag{18}$$

where A is the area of the conducting plates, the factor 2 accounts for the two polarizations.

Turning to polar coordinates in two dimensions by setting $r^2 = k_y^2 + k_z^2$ and performing the angular integration, we arrive at the density of energy per surface

$$\frac{E(d)}{A} = \frac{\hbar c}{2\pi} \sum_{n=1}^{+\infty} \int_0^{+\infty} \mathrm{d}r \, r \sqrt{\frac{n^2\pi^2}{d^2} + r^2}. \tag{19}$$

As it stands, this integral is strongly divergent. As a regularization measure, we multiply everything by ω_n^{-a} and eventually let $a \to 0$. The expression we obtain is given by

$$\frac{E(d)}{A} = \frac{\hbar c^{1-a}}{2\pi} \sum_{n=1}^{+\infty} \int_0^{+\infty} \mathrm{d}r \, r \left(\frac{n^2\pi^2}{d^2} + r^2\right)^{\frac{1-a}{2}}, \tag{20}$$

and this integral is well behaved for $\Re(a) > 3$. Performing the integration, we arrive at

$$\frac{E(d)}{A} = -\frac{\hbar}{2\pi} \frac{c^{1-a}}{3-a} \left(\frac{\pi}{d}\right)^{3-a} \sum_{n=1}^{+\infty} n^{3-a}, \tag{21}$$

the sum on the rhs is recognized to be the zeta function, $\zeta(a-3)$, which is not singular for $a = 0$ and assumes the value $\zeta(-3) = 1/120$. The complete zero point energy density in three dimensions is therefore given by the expression:

$$\frac{E(d)}{A} = -\frac{\pi^2}{720} \frac{\hbar c}{d^3} \, . \tag{22}$$

It is worth noticing that in $3D$ a different geometry of the plates in the Casimir effect could change the sign of the force making it, say, attractive instead of repulsive.

As a byproduct, we have just “proved” that

$$1 + 2 + 3 + 4 + 5 + \ldots = -\frac{1}{12} \, . \tag{23}$$

The Casimir effect has been explicitly shown here for two parallel plates in 1D and 3D respectively, and the force is attractive.

There are many more possible situations in which the effect could be observed. Lifshits (Lifshitz, 1956) studied the case of two parallel dielectric bodies and the effects of finite temperature; the case of a liquid layer of separation was studied by Dzyaloshinskii, Lifshitz and Pitaevskii (Dzyaloshinskii et al, 1961). They also showed that, under certain circumstances, the Casimir force could be repulsive rather than attractive. Schwinger (Schwinger, 1951, 1975) studied the problem; in (Schwinger, 1992a) he used a different approach from the effective action, and in (Schwinger, 1992b,c), he started the calculations for a spherically shaped object.

References

Casimir, H.B.G. 1948. On the attraction between two perfectly conducting plates. *Proc. Kon. Ned. Akad. Wet.*, 51, p.793 [online]. Available at: https://dwc.knaw.nl/DL/publications/PU00018547.pdf [Accessed: 18 November 2022].

Casimir, H.B.G. 1953. Introductory remarks on quantum electrodynamics. *Physica*, 19(1-12), pp.846-849. Available at: https://doi.org/10.1016/S0031-8914(53)80095-9.

Casimir, H.B.G. & Polder, D. 1948. The Influence of Retardation on the London-van der Waals Forces. *Physical Review*, 73(4), pp.360-372. Available at: https://doi.org/10.1103/PhysRev.73.360.

Dzyaloshinskii, I.E., Lifshitz, E.M. & Pitaevskii, L.P. 1961. General Theory of van der Waals' Forces. *Soviet Physics Uspekhi*, 4(2), pp.153-176. Available at: https://doi.org/10.1070/PU1961v004n02ABEH003330.

Fabiano, N. 2020. Zeta function and some of its properties. *Vojnotehnički glasnik/Military Technical Courier*, 68(4), pp.895-906. Available at: https://doi.org/10.5937/vojtehg68-28535.

Fabiano N. 2021. Corrections to propagators of quantum electrodynamics. *Vojnotehnički glasnik/Military Technical Courier*, 69(4), pp.930-940. Available at: https://doi.org/10.5937/vojtehg69-30604.

Fabiano N. 2022. Regularization in quantum field theories. *Vojnotehnički glasnik/Military Technical Courier*, 70(3), pp.720-733. Available at: https://doi.org/10.5937/vojtehg70-34284.

Lifshitz, E.M. 1956. The Theory of Molecular Attractive Forces between Solids. *Journal of Experimental and Theoretical Physics (JETP)/Soviet Physics*, 2(1), pp.73-83 [online]. Available at: http://jetp.ras.ru/cgi-bin/e/index/e/2/1/p73?a=list. [Accessed: 18 November 2022].

Schwinger, J. 1951. On Gauge Invariance and Vacuum Polarization. *Physical Review*, 82(5), pp.664-679. Available at: https://doi.org/10.1103/PhysRev.82.664.

Schwinger, J. 1975. Casimir effect in source theory. *Letters in Mathematical Physics*, 1(1), pp.43-47. Available at: https://doi.org/10.1007/BF00405585.

Schwinger, J. 1992a. Casimir energy for dielectrics. *PNAS*, 89(9), pp.4091-4093. Available at: https://doi.org/10.1073/pnas.89.9.4091.

Schwinger, J. 1992b. Casimir effect in source theory II. *Letters in Mathematical Physics*, 24(1), pp.59-61. Available at: https://doi.org/10.1007/BF00430003.

Schwinger, J. 1992c. Casimir effect in source theory III. *Letters in Mathematical Physics*, 24(3), pp.227-230. Available at: https://doi.org/10.1007/BF00402898.

Эффект Казимира

Никола Фабиано
Белградский университет, Институт ядерных исследований «Винча» − Институт государственного значения для Республики Сербия, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 29.05.03 Математические методы теоретической физики,
29.05.23 Релятивистская квантовая теория. Квантовая теория поля
29.05.33 Электромагнитное взаимодействие
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Квантование электромагнитного поля порождает квантовые флуктуации, которые, в свою очередь, создают силу на макроскопических границах. Этот феномен называется эффектом Казимира.

Методы: В данной статье используется вторичное квантование электромагнитного поля. Также применяется метод регуляризации с помощью дзета-функции.

Результаты: В результате квантования электромагнитного поля на макроскопических границах наблюдается сила.

Выводы: Флуктуации вакуума из-за квантовых эффектов дают макроскопические результаты.

Ключевые слова: квантовая электродинамика, квантование, энергия вакуума, эффект Казимира.

Казимиров ефекат

Никола Фабиано

Универзитет у Београду, Институт за нуклеарне науке „Винча” - Институт од националног значаја за Републику Србију, Београд, Република Србија

ОБЛАСТ: математика
КАТЕГОРИЈА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Квантизација електромагнетног поља доводи до квантних флуктуација које заузврат производе силу на макроскопским границама. Овај феномен назива се Казимиров ефекат.

Методе: Користи се друга квантизација електромагнетног поља. Примењена је техника регуларизације помоћу зета-функције.

Резултати: Због квантизације електромагнетног поља примећује се сила на макроскопским границама.

Закључак: Флуктуације вакуума услед квантних ефеката дају макроскопске ефекте.

Кључне речи: квантна електродинамика, квантизација, енергија вакуума, Казимиров ефекат.

Paper received on / Дата получения работы / Датум пријема чланка: 20.11.2022.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 12.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 14.06.2023.

Data security in mobile healthcare

Marija B. Zajeganović[a], *Natalija* J. Vugdelija[b],
Radiša R. Stefanović[c], *Silva* M. Kostić[d],
Uroš D. Miljković[e], *Georg* G. Mach[f]

[a] Academy of Technical and Art Applied Studies Belgrade,
Department School of Information and Communication Technologies,
Belgrade, Republic of Serbia,
e-mail: marija.zajeganovic@ict.edu.rs, **corresponding author**,
ORCID iD: https://orcid.org/0000-0002-6525-1949

[b] Academy of Technical and Art Applied Studies Belgrade,
Department School of Information and Communication Technologies,
Belgrade, Republic of Serbia,
e-mail: natalija.vugdelija@ict.edu.rs,
ORCID iD: https://orcid.org/0000-0002-4051-3148

[c] The Academy of Applied Technical Studies Belgrade,
Department of Applied Engineering Sciences,
Požarevac, Republic of Serbia,
e-mail: rstefanovic@atssb.edu.rs,
ORCID iD: https://orcid.org/0000-0001-5497-3826

[d] Academy of Technical and Art Applied Studies Belgrade,
Department School of Information and Communication Technologies,
Belgrade, Republic of Serbia,
e-mail: silva.kostic@ict.edu.rs,
ORCID iD: https://orcid.org/0000-0002-7766-6391

[e] FH Campus Wien - University of Applied Sciences,
Vienna, Republic of Austria,
e-mail: uros.miljkovic@fh-campuswien.ac.at,
ORCID iD: https://orcid.org/0009-0007-2416-0649

[f] FH Campus Wien - University of Applied Sciences,
Vienna, Republic of Austria,
e-mail: georg.mach@fh-campuswien.ac.at,
ORCID iD: https://orcid.org/0009-0001-3538-6228

DOI: 10.5937/vojtehg71-44245; https://doi.org/10.5937/vojtehg71-44245

FIELD: telecommunications, IT
ARTICLE TYPE: review paper

ACKNOWLEDGMENT: The authors would like to thank the Heliant company for providing information about the applied technologies in the health information system and the implemented projects in Serbia in the field of e-health.

Abstract:

Introduction/purpose: The digitization of healthcare has gained particular importance in the years since the emergence of COVID-19 and also has become one of the primary goals of the Government of the Republic of Serbia. Telemedicine is a good solution when the patient cannot come to a healthcare facility. Mobile healthcare applications are already widely used, but in both fields the important challenge is data security. The aim of this paper is to review solutions for data security in mobile healthcare from the technical side and possible challenges in the process of digitization of the healthcare system in Serbia.

Methods: This review is based on current papers in this area, on the available relevant literature and the authors' many years of experience in this field. Experiences in the process of digitization of healthcare in Serbia are based on available articles and regulations. Finally, possible challenges are presented from the authors' perspective based on everything presented in the field of data security in mobile healthcare.

Results: The analysis of the papers reviewed from the point of view of data security showed that users are often ready to sacrifice their privacy for the sake of convenience provided by mobile applications.

Conclusion: Based on the review of the papers and clear data security requirements that include the presented safeguards, one of the main tasks of the entire community is to raise awareness of information security and awareness of the need for cyber hygiene of each individual, which is the basis for the safe use of e-health services.

Key words: information security, e-health, telemedicine, mobile healthcare, attacks, attack prevention.

Introduction

Mobile healthcare (mHealth) refers to the application of mobile technologies in healthcare, including mobile applications, wearable devices, telemedicine, and other technologies that enable quick and easy exchange of medical data and information.

Information security in mHealth is of particular importance to ensure that medical data is stored securely and to maintain the patient's privacy. It is important to implement all security measures to ensure the data is protected from unauthorized access or misuse.

When it comes to information security in mobile healthcare, there are several key factors to consider: data transfer security, user authentication, device security, regulatory compliance, and software security.

Healthcare mobile applications use data encryption, which means that all data transmitted is encrypted and protected from unauthorized access.

Encryption means that data is converted into an encrypted form before it is transmitted via the Internet, and only authorized persons with the right key can decrypt the data. Applications may implement other security measures, such as user authentication by using passwords, biometrics, or two-factor authentication, access control, and regular software updates to ensure data security.

Apps often provide privacy settings, allowing users to decide what data is shared with others and how. This includes sensitive medical data, such as data on health and medical conditions, as well as other types of data may be collected, such as data on physical activity, diet, sleep and other factors that may affect health, which can help users maintain a healthy lifestyle and improve their health. Depending on the type and sensitivity of the data, some is stored on servers in accordance with the law on the protection of personal data, which prescribes obligations and responsibilities related to the processing of personal data, while some is stored on mobile devices themselves, so users of these applications should be aware that they should apply security measures themselves, such as locking the device's screen, not using unsecured Wi-Fi networks, and not installing suspicious applications. Therefore, it is important to emphasize that in the case of mobile healthcare, when it comes to sensitive medical data, data security does not only refer to data storage on servers, but also on users' mobile devices. In any case, the data must be stored securely. This can be achieved by applying encryption or remotely erasing the data in case the device is lost or stolen. It is also necessary to comply with laws and regulations to ensure the legality and security of medical data processing.

Software used in mobile healthcare must be safe and secure. When developing and testing applications, security standards should be applied to ensure protection against hacker attacks or other types of cyberattacks. When creating a database, designers should adhere to the best practices and security standards, such as the GDPR (General Data Protection Regulation) and the HIPAA (Health Insurance Portability and Accountability Act), to ensure user privacy protection and regulatory compliance in the field of personal and health data protection.

Security of information systems

The term cybersecurity implies the protection of digital information, devices and resources. John McCumber (McCumber, 2004, pp.99-107) developed a network security management tool that he named the Cybersecurity Cube (Figure 1).

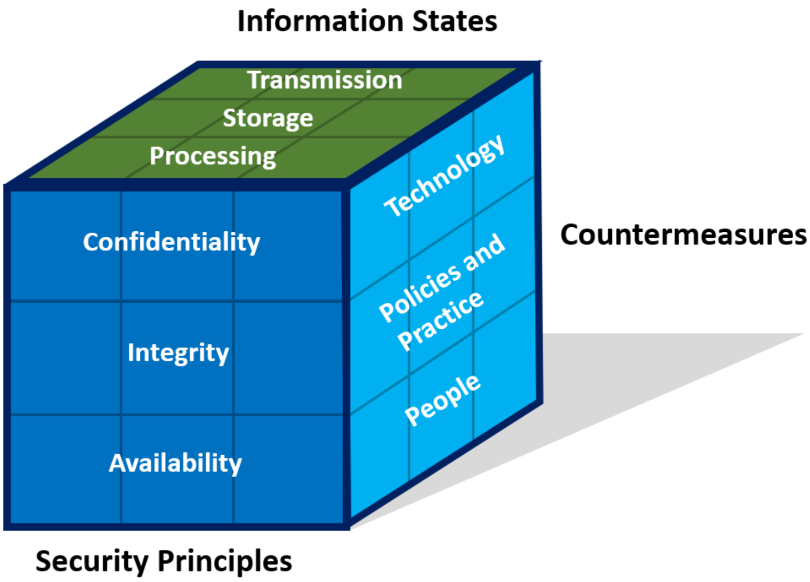


Figure 1 – Cybersecurity Cube
Рис. 1 – Куб кибербезопасности
Слика 1 – Коцка сајбер безбедности

Like any cube, it has three dimensions that represent one of the tools for a comprehensive approach to information systems security. The first dimension of the cube includes the three principles of information security (CIA triad). The second dimension identifies three data states. The third dimension of the cube represents protective measures.

Principles of information security

In telecommunications, i.e., computer systems that enable data transmission, it is necessary to consider three key principles that form the core of security and represent desired goals when it comes to information security: confidentiality, integrity and availability, i.e., the so-called CIA triad (Stallings, 2014).

Confidentiality is assurance that information is neither intentionally nor accidentally disclosed to unauthorized persons. Confidentiality encompasses two related concepts: data confidentiality and privacy. Data confidentiality ensures that information is not disclosed to or made available to unauthorized individuals. Privacy means that individuals control and influence what personal information may be collected and stored, who may do so, and to whom that information may be disclosed.

Zajeganović, M. et al, Data security in mobile healthcare, pp.748-768

Integrity is a guarantee that the information has not been modified either accidentally or intentionally, thereby guaranteeing its credibility. In this sense, data integrity and system integrity should be taken into account. Data integrity guarantees that information and programs are not changed, that is, that they are changed only in a specific and authorized way. System integrity guarantees that the system performs the functions for which it is intended in an uninterrupted manner, protected from intentional, unintentional, and unauthorized manipulation of the system.

Availability ensures that the systems work quickly, that is, without delay, and that the service is not denied to authorized users who should have timely and secure access to data and other resources.

The use of the CIA triad to define security goals is often supplemented with two more concepts: authenticity and accountability. Authenticity is the property of being able to trust the validity of the transmission of messages, the validity of the message itself, and the validity of the source of the message. Accountability is a security goal that supports non-repudiation and allows for the traceability of possible security breaches as truly secure systems are not yet achievable, so systems must keep activity logs to enable forensic analysis in the event of a security breach.

Data states

Cyberspace is a domain that contains a significant amount of sensitive information, and therefore the second dimension of the Cybersecurity Cube is the state of the data, because it is important to protect the data in each of the possible states.

Data at rest (storage) is the data which is stored while no user or process is using it. It can be stored locally on a device or centrally in a network. Data storage can be directly attached storage (DAS, Direct-Attached Storage) such as hard disks, USB flashes and similar, as well as RAID (Redundant Array of Independent Disks) which provide improved performance and fault tolerance. There are also network storage devices such as NAS (Network Attached Storage), and storage networks, SAN (Storage Area Network). A remote data storage option is cloud data. Each of the mentioned warehouses has specific challenges when it comes to their protection. Direct-attached storage is the most difficult type to manage and control, while network systems are a more secure option due to better performance and redundancy. On the other hand, network storage systems are more complicated to configure, so proper configuration, testing, and monitoring of such a system are extremely important.

Data in transmission is data transferred from one device to another. This can be done by using removable media to physically move data from one device to another (sneaker net) and over a wired or wireless computer network. Through computer networks, data is transmitted in accordance with standard protocols that are available to the public. Protecting the confidentiality, integrity and availability of transmitted data is one of the most important responsibilities of a cyber security professional. Protection of data in transmission is implemented through various technologies and protocols such as VPN (Virtual Private Network), SSL/TSL, IPsec, etc.

Data in processing is the third state of data that refers to data during initial input, modification, calculation, or during output. Data integrity protection begins with the initial data entry. Errors during input, data reading, faulty sensors or mismatched data formats are examples of data corruption during input. Data modification during encoding/decoding, compression/expansion, encryption/decryption is a stage where integrity can be damaged by a malicious code. Data protection during processing requires well-designed systems. Cybersecurity professionals create policies and procedures that require testing, maintaining, and updating systems to keep them functioning with the least amount of errors.

Protective measures

The third dimension of the Cybersecurity Cube defines the skills and disciplines that can be used to protect cyberspace. These include technologies, human factors, and security policies.

Technologies for the protection of information systems can be based on software, hardware, network, or cloud. Software protections include programs and services that protect operating systems, databases, servers and end devices. Software firewalls protect remote access to the system. Hardware protection includes firewall devices that block unwanted traffic. Protection at the level of network technologies provides protected transmission such as VPN (Virtual Private Network), protected access to network devices (NAC Network access control) and authentication and encryption for wireless access. Cloud service providers use virtual security appliances that run in a virtual environment with a security-enhanced operating system running on virtualized hardware.

The human factor is often the weakest link in cyber security. Protective measures primarily include security awareness programs, which should be a constant process because new techniques and new threats are always present. People may not be intentionally malicious, but simply unaware of the consequences of not following security procedures. Establishing a culture of cyber security awareness should be implemented through formal education from early childhood to active security awareness programs in work organizations. Cyber security experts are also included in the protective measures. This is a particular challenge for education in the IT sector. A cyber security expert must master all techniques mastered by an attacker and must stay one step ahead of the attacker. Ethical hacking is a significant process in educating and creating cyber security professionals.

A security policy is a set of security goals that include rules of conduct for users and administrators. A comprehensive security policy must be clearly defined. Security policy usually includes identification and authentication policy, password policy, network resource usage policy, remote access policy, computer network maintenance policy, incident handling policy, etc. Standards help IT staff maintain consistency in network operation. Guidelines define how standards are developed and guarantee compliance with general security policies. Some of the most useful guidelines are good practices from organizations. Procedures are documents that are more detailed than standards and guidelines and include details of security policy implementation that usually contain step-by-step instructions and diagrams.

E-health

E-health is a branch of medical informatics that refers to the application of information and communication technologies for the provision of health services and health information. Thus, e-health promotes the sharing of health information, provides effective health care, and enables patients to manage their own health. The goal of e-health is to transform the healthcare system into a patient-centered model.

The COVID-19 pandemic has contributed to the increase in the research and development of e-health systems. Although there are many aspects, three areas can be singled out as key areas: the architecture of e-health, the development of mobile healthcare technologies, and the field of security of e-health systems (Alenoghena et al, 2022). E-health includes health informatics, electronic health record, electronic entry of medical orders, electronic prescriptions, telemedicine, and mobile healthcare.

Telemedicine

Telemedicine involves the use of information and communication technologies in order to provide health services to remote patients and to facilitate the exchange of information between the primary service of a doctor or medical staff and a specialist, or an expert in a subspecialty.

Distance is the motive for the development of this area, which arose from the need to facilitate the treatment of patients in rural areas, that is, to provide adequate first aid in emergency cases (Reljin & Gavrovska, 2013). Telemedicine is a multidisciplinary field that includes processing, transmission, storing and searching of data that often include multimedia and have high requirements related to quality, flow, reliability, and protection.

There are three basic types of telemedicine: store and forward, remote monitoring, and real-time interactive services. Store and forward is a method where the sender has all information, and forwards to the recipient when it suits them. Remote monitoring implies that the patient's health is checked using various technical means and thus clinical indicators about them are obtained remotely. In the case of an interactive service, the doctor and the patient are online and the transfer of information is live and two-way between them. Within telemedicine, there are branches such as telecardiology, teleradiology, telepsychiatry, telesurgery, etc.

Mobile healthcare

Mobile healthcare is a technology that enables the application of e-health anytime and anywhere, which implies the use of mobile telecommunications and new network technologies. The term digital health, in addition to the already mentioned e-health, also includes the use of sophisticated computer sciences such as "big data" and artificial intelligence. The components of mobile health are wireless sensors, mobile devices, and communication technologies. Wireless sensors are used in the medical field to collect data on the condition of patients. Mobile devices enable the transmission of data, sound and images via a wireless connection, regardless of where they are. Communication technologies used in mobile healthcare are primarily short range systems (Bluetooth, Zigbee), WiFi, mobile cellular systems (2G, 3G, 4G, 5G), and satellite systems.

Mobile healthcare (mHealth) is defined by the World Health Organization (WHO) as mobile applications and wearable devices that are used for health care. Mobile apps are software programs used by mobile phones and tablets, while mHealth App are mobile applications used for health care.

The growing number of mobile applications including mHealth applications leads to increased access to health data. Research shows that many of the most popular mHealth apps for women on the market have poor data protection and security standards (Alfawzan et al, 2022).

Although there are regulation, such as the EU GDPR (European Union General Data Protection Regulation), research shows that the regulations are not always followed in practice. A large number of medical, health and fitness applications can collect and potentially share data with third parties without always being transparently presented (Tangari et al, 2021). Mobile applications are rapidly becoming a source of information and decision support tools for both clinicians and patients. Such privacy risks should be presented to patients and may be part of consent when using a mobile application. Primarily, mHealth applications help users manage their health and receive health services. Research shows that people take responsibility for the risks while evaluating benefits when faced with a choice (Zhou et al, 2019). The advantages provided by mHealth applications, such as convenience, real-time health care, time saving and often free use, may outweigh the security and privacy risks, so users are willing to sacrifice privacy for the convenience that mHealth applications provide (Schroeder et al, 2022).

Data security in e-health

The CIA (Confidentiality, Integrity, Availability) triad represents the basic principle of information security, and it also applies to data security in e-health. Confidentiality guarantees that data will not be disclosed by unauthorized persons. This becomes even more important in mobile healthcare. First of all, information itself is sensitive, i.e., patient privacy must be protected. Second, wireless transmission and the very architecture of the network makes that data available to a large number of users, so there is a risk of its being compromised. That is why data encryption is necessary. Different types of encryption provide different levels of protection (Zajeganović et al, 2019). Integrity refers to the fact that the data has not been altered, which is of great importance when it comes to the data sent and recorded within e-health. This is accomplished using hashes or checksums. If the integrity check fails, the application must report an error and close without any data processing. And finally, the availability that allows the data to be always available when needed, is an extremely important condition because the patient's life can be threatened if they are denied medical services. The HIPAA (Health Insurance Portability and Accountability Act) security rule requires the protection of sensitive health information about a patient, which means that that information will not be disclosed without the consent or knowledge of the patient. Authentication processes are varied and standards are constantly evolving. Biometric methods are involved in that process to a great extent (Tot et al, 2021a). The field of development and standardization of methods for biometric authentication is certainly one of the most important ones, and there is a large space for research in this area (Tot et al, 2021b).

In order for the data to be safe, it is necessary to have a secure computer network. The security of computer networks is a prerequisite for secure data transmission.

Threats and attacks in the computer network

Threats and attacks in a computer network are very diverse and difficult to classify. The list of possible attacks is constantly increasing because different techniques for exploiting system vulnerabilities are continuously being developed. The specificity of the attack can also be related to the type of network infrastructure. In case of wireless communications, there are very specific attack techniques (Stefanović & Pavlović, 2013). Attacks can be divided into those that come from outside, from the Internet, and those that come from inside the network. Cyber attacks in a broader sense can also be divided depending on which layer of the OSI model they attack (Mitić et al, 2020) so we can classify them into:

- Attacks on the second layer (Layer 2 attacks) - attacks in the LAN network on one broadcast domain,
- Attacks by protocols (Protocols Attack) - attacks on routing protocols (RIP, OSPF, EIGRP, BGP), attacks on DHCP (Dynamic Host Configuration Protocol), HSRP (Hot Standby Routing Protocol), CDP (Cisco Discovery Protocol), ICMP (Internet Control Message Protocol),
- Quantitative attacks - attacks where attackers send a large amount of traffic over the botnet that exceeds the available flow capacity of the victim, and
- Application attacks - attacks that use vulnerabilities in applications and operating systems.

The list of frequent attacks on the computer network consists of:

- eavesdropping,
- data modification,
- IP address spoofing attack,
- password-based attacks,
- Denial of Service (DoS) attack,
- Man-in-the-Middle attack,
- compromised key attack, and
- sniffer.

The above list only represents some of the common computer network attacks. The tools used by attackers are also diverse and their sophistication is constantly increasing. The decryption process is definitely being accelerated by the development of computer technology, but it is unlikely that it will completely replace the role of humans (Stefanović & Srdanov, 2014). In the past, the tools were not so sophisticated and the attackers had to have a lot of knowledge about networks, while today the situation is completely different . The user of the attack tools does not need to have any technical knowledge. Today, even cybercrime is offered as a service and cybercriminals, malware developers and other participants in the cybercrime infrastructure sell their services to potential clients. However, in contrast to cybercriminals (black hat hackers) there are also benevolent hackers (white hat hackers) who use the same tools, but with the aim of finding system vulnerabilities in order to improve their protection. The list of attack tools is not exhaustive and is constantly growing. However, the following are some of the commonly used cyber attack tools:

- password cracking tools,
- tools for hacking wireless networks,
- network scanning and hacking tools,
- tools for creating fake packages,
- packet capture and analysis tools,
- Rootkit detectors,
- tools for detecting, scanning and exploiting vulnerabilities,
- forensic tools,
- operating systems with hacking tools, and
- encryption tools.

In order for hackers to access the system and apply any of the tools mentioned above, they need to compromise the respective device, which is done by some of the malicious software such as:

- different types of viruses,
- different types of Trojans,
- worms,
- adware,
- ransomware,
- spyware, and
- rootkit.

Finally, in order to develop a new attack technique, a good knowledge of the functioning of the system as well as the vulnerabilities that the system has in order to exploit these vulnerabilities is necessary. The overview of cyber attacks, protection techniques and their recognition is inexhaustible because with the development of new technologies, new types of attacks appear as well as techniques for detecting and preventing cyberattacks. Since there is no perfect protection, it is necessary to combine different protection techniques and educate users on how to protect their accounts (Vugdelija et al, 2021). Vulnerability detection is primarily the task of well-intentioned attackers whose goal is to improve system security. Ethical hacking is precisely the field of cyber security that deals with this.

Cyberattack protection techniques

As cyberattack techniques advance, so does the defense, that is, the response to the attack. To defend a larger network, dedicated protection devices are used at the Internet exit. Different software solutions such as antivirus, antimalware and firewall are used for individual defense. Restrictions are set on routers in the form of access lists. More sophisticated devices such as dedicated firewalls can filter traffic by checking the header at higher layers of the OSI model such as Intrusion Prevention System (IPS) and Intrusion Detection System (IDS) firewalls such as ASA (Adaptive Security Appliance) devices and ISR (Integrated Services) Routers), then ESA/WSA (Email Security Appliance/Web Security Appliance) that filter spam emails and prevent access to suspicious sites that have malicious software, as well as AAA servers (Authentication, Authorization and Accounting) that allow access only to authorized users. As stated earlier, cryptography is one of the basic methods of data protection and the trend is to encrypt all data. Secure communication has the following four elements: data integrity, provenance, data confidentiality, and data non-repudiation. This is achieved by appropriate techniques such as: symmetric and asymmetric encryption, hash functions, digital signature, and digital certificates (Zajeganović et al, 2019).

Complete protection against cyberattacks is difficult to achieve because there are many links in that defense chain, of which the human being is one of the weakest, so the way to improve security is the so-called zero-trust architecture (Zero-Trust Security Model).

Digitization of healthcare in Serbia

Digitalization program in the healthcare system of the Republic of Serbia for the period 2022 - 2026 adopted by the Government of the Republic of Serbia provides recommendations, i.e., measures that should be taken in order to digitize and comprehensively modernize healthcare, so as to obtain connected, efficient, and better quality healthcare.

One of the special goals is the establishment of a secure and integrated information and communication infrastructure and electronic services. In order to achieve this goal, among other things, legal frameworks related to the security of sensitive health information that is used, exchanged and stored, as well as the rights of access to that data, are necessary. New technologies are introducing solutions that allow healthcare professionals to communicate with patients remotely and opening the door to the use of telemedicine devices for remote monitoring of the patient's condition. The Government of the Republic of Serbia has foreseen that eHealth provides other possibilities in terms of electronic regulation of sick leave, renewal of electronic prescriptions, requests for issuance and renewal of health insurance cards, insight into the costs of health services provided, participation in the selection of options for locations for the provision of health services, receiving advice from health workers about the prescribed therapy and treatment. Certainly, in order to achieve this, a coordinated activity of adapting already existing software programs and developing new ones is needed. In Serbia, there is an IZIS (integrated Health Information System) and all data exchanged must comply with the existing standards, including data security.

A special challenge in terms of data security and privacy is the establishment of a system for collecting depersonalized data periodically or in real time for the purposes of analytics and reporting, as well as operational data on the use of resources in the health system. This would enable the improvement of a decision-making system based on machine-readable data, analysis, and reports.

Above all, the basis on which everything rests is the computer network, technologies for remote data transmission as well as the availability of network devices and servers. In this sense, all system should have resources and procedures for back-up so that all data would be saved in case of failure for any reason, including cyberattacks.

In the Republic of Serbia, the process of digitizing the healthcare system began several years ago but the COVID-19 pandemic made people more aware of the need and importance of remote treatment and the use of mobile applications in healthcare, and accelerated this process by placing it among the priority tasks on the way to the e-society.

Telemedicine in Serbia

The modern telemedicine program started in Europe in 1988 (Reljin & Ćućuz, 2007), and Serbia did not lag behind. Although in the 90s there was a difficult situation in the country due to sanctions, hyperinflation and war actions, 1995 saw the beginning of the digitization of the large library of classic glass slides at the Military Medical Academy (VMA) at the Institute of Pathology and Forensic Medicine, and in 1997 Telemedicine Center was established at the VMA and a permanent telepathological connection was established between the VMA in Belgrade and the Military Hospital and Institute of Pathology of the Faculty of Medicine in Niš. The VMA had several experimental connections with other medical centers: in Podgorica, Sremska Kamenica, and with KBC Bežanijska Kosa.

Medical institutions in Serbia have been faced with a lack of professional staff for decades, and for this reason, in 2012, the Project "Introduction of Telemedicine in Eastern Serbia" was launched. The Project was implemented by the National Alliance for Local Economic Development (NALED) and the "Merck Sharp & Dohme" (MSD) foundation, and within a year, the idea came to fruition. The health center in Boljevac is connected with the Zaječar Health Center and the Clinical Center in Niš by means of telecommunication equipment. The biggest challenge for the implementation of telemedicine is providing good equipment and support to patients and doctors.

After these pioneering efforts, subsequent projects in the field of e-health were supported by the Government of the Republic of Serbia, so that today, for more than a year, patients can be examined through the Heliant Telemedicine platform at KBC Zvazdara, in which the service is intended for patients suffering from inflammatory bowel disease. This kind of service should take root in other areas of medicine as well.

Mobile healthcare in Serbia

As mentioned earlier, mobile healthcare includes mobile applications and wearable devices used for health care. The importance of mobile healthcare is also shown by the fact that since the Apple smart watch was registered as a medical device, more and more people appeared who did not know they had cardiac arrhythmias, and received a warning from such a watch. Of course, there are far more specialized devices used in mobile healthcare to monitor the health of patients, such as smart pressure gauges that, in addition to analyzing blood pressure and heart rate, monitor ECG and heart sounds, and all these results can be made available to the doctor for further analysis. In addition to specialized devices, there are also mobile applications that allow monitoring and saving of recorded health data that can be used for further analysis. The fact that devices like smart watches and mobile phones can be made into medical devices with the right mobile apps makes it easier for people to get involved in the process of taking care of their health.

Various mobile applications for health care are available in Serbia. In cooperation with the Multiple Sclerosis Society of Serbia, the Heliant company developed the mobile application My MS World. The application is conceptually divided into three units. The first part consists of educational content, the second part represents support for patients in fulfilling their daily activities, and the third part contains information about therapeutic methods, and questionnaires and tests that help self-assessment of patients' health status. There are a number of mobile applications whose development was initiated by the corresponding association, so the MyMelanoma application was prepared by the Association of Melanoma Patients, while the MojRA application was prepared by the Association of Rheumatic Diseases of Serbia, and the HemApp application was prepared by the Association of Hemophiliacs of Serbia. After successful implementations in Serbia, the same applications were implemented in Montenegro (MojRA ME, HemApp ME). The ONKO application was created as part of the "Knowledge Against Cancer" project of the Institute of Oncology and Radiology of Serbia and is motivated by the idea of making it easier for patients to access the Institute of Oncology and Radiology of Serbia and to enable them to have the right information when it comes to the treatment of malignant diseases. The Open the Blue Circle (OPK) mobile application, which is part of the Cities Change Diabetes project, was developed to promote healthy lifestyles and thereby influence the prevention of diabetes. UNICEF in Serbia and the City Public Health Institute of Belgrade have developed a Bebbo mobile application to support parenting and monitor children's development from birth until they start school, and in addition to reminders for preventive pediatric examinations and immunisation schedule, it also suggested how to enrich family routines through games or how to set healthy boundaries for your child when it comes to behavior. Therefore, mobile applications used in mobile healthcare, in addition to health data and information, often have recommendations and activities that are generally related to a healthy lifestyle, both physical and mental, in order to prevent various diseases.

In mobile applications used for health care, general information is stored on servers, and personal data is stored on the mobile phone itself and cannot be accessed by anyone other than that user. For any other data processing and storage of personal information in a place other than the phone, it is necessary to give the appropriate consent. Privacy rights and data security should be respected in all applications.

Data security

Since the beginning of remote treatment, the security of communication itself and the security of data are topics that must not be bypassed. This must be looked at from both technical and legal aspects. Legal acts related to the security of e-health and e-government in Serbia have been adopted. There is also the ConsentID application that can be used when signing up for eHealth and other e-services available to citizens of Serbia. The ConsentID application enables authentication when accessing the e-service, which is connected to the citizen's qualified electronic certificate. The portal for electronic identification, eid.gov.rs, enables access with different degrees of privileges, as well as the possibility of having a qualified electronic certificate in the cloud and a signature in the cloud.

Communication via the Heliant Telemedicine platform takes place via a video link generated through the Hedex (Heliant Data Exchange) service. Data servers are e-government servers. The mobile application "My MS World" stores data on the servers in Kragujevac, and for now there is much more informative content there than personal data, and work is being done, in cooperation with Heliant, to improve the application.

Finally, when it comes to data security in e-health, whether it is about telemedicine services or mobile applications used in healthcare, the biggest challenge is to design the system well enough from the point of view of security and privacy of sensitive personal data. Software designers need precise information about who can or must access which data in order to keep data systems connected, to properly create roles and access rights for different types of data. In this sense, in addition to technical, legal regulation is also necessary based on which requirements would be clearly defined. The topic of data security, especially when it comes to healthcare data, must be approached both from a technical and legal perspective.

Conclusion

The aim of this review paper is to present the basic principles of information security as well as their application in technologies used in mobile healthcare, given that information security is of great importance in healthcare in general, and especially in the field of electronic healthcare due to the challenges that inevitably arise in that process.

Human error is the biggest problem for information security. Although many companies invest heavily in vulnerability scanning, antivirus programs, software updates, and more, the problem of undertrained employees remains. That is why it is of great importance that both employees and users are regularly trained in this area and that the awareness of information security is raised among all individuals. One of the main tasks of the entire community, above all the state, which has set the digitalization of society as its strategic goal, should be to raise awareness of information security and awareness of the need for cyber hygiene of every individual, either as an employee at the workplace or as a user of e-services. This is the only way to build an e-society that will safely use the services of e-government, e-health, etc.

References

Alenoghena, C.O., Onumanyi, A.J., Ohize, H.O., Adejo, A.O., Oligbi, M., Ali, S.I. & Okoh, S.A. 2022. eHealth: A survey of architectures, developments in mHealth, security concerns and solutions. *International Journal of Environmental Research and Public Health*, 19(20), art.number:13071. Available at: https://doi.org/10.3390/ijerph192013071.

Alfawzan, N., Christen, M., Spitale, G. & Biller-Andorno, N. 2022. Privacy, Data Sharing, and Data Security Policies of Women's mHealth Apps: Scoping Review and Content Analysis. *JMIR mHealth and uHealth*, 10(5), e33735. Available at: https://doi.org/10.2196/33735.

McCumber, J. 2004. *Assessing and managing security risk in IT systems: A structured methodology, 1st edition*. New York: Auerbach Publications. ISBN: 9780429208409.

Mitić, M., Zajeganović, M., Kurbalija, N., Čabarkapa, S. & Pavlović, M. 2020. Web server security. In: *15th International conference on Risk and safety engineering*, Kopaonik, Serbia, pp.250-256, January 16-18 [online]. Available at: http://www.rizik.vtsns.edu.rs/RSE_2020/radovi/05/RIZIK_05_3.pdf (in Serbian) [Accessed: 20 April 2023]. ISBN: 978-86-6211-124-1.

Reljin, B. & Ćućuz, V. 2007. Project telepathology network. In: *XXV Simpozijum o novim tehnologijama u poštanskom i telekomunikacionom saobraćaju - PosTel 2007*, Belgrade, pp.101-108, Decembar 11-12 [online]. Available at: https://postel.sf.bg.ac.rs/simpozijumi/POSTEL2007/RADOVI%20PDF/(3)%20-%20MULTIMEDIJA/03-Reljin%20Cucuz.pdf (in Serbian) [Accessed: 20 April 2023]. ISBN: 978-86-7395-243-7.

Reljin, I. & Gavrovska, A. 2013. *Telemedicina*. Belgrade: Akademska misao (in Serbian). ISBN: 978-86-7466-458-2.

Stallings, W. 2014. *Osnove bezbednosti mreža: aplikacije i standardi*. Belgrade: School of Computing & CET (in Serbian). ISBN: 978-86-7991-376-0.

Stefanović, R.R. & Pavlović, B.Z. 2013. Safety of routing protocols in ad hoc networks and possible attacks in the network. *Vojnotehnički glasnik/Military Technical Courier*, 61(2), pp.200-217 (in Serbian). Available at: https://doi.org/10.5937/vojtehg61-1826.

Stefanović, R.R. & Srdanov, A.S. 2014. Use of computers for decrypting messages. *Vojnotehnički glasnik/Military Technical Courier*, 62(2), pp.96-108 (in Serbian). Available at: https://doi.org/10.5937/vojtehg62-3831.

Tangari, G., Ikram, M., Ijaz, K., Kaafar, M.A. & Berkovsky, S. 2021a. Mobile health and privacy: cross sectional study. *BMJ*, 373, art.number: 1248. Available at: https://doi.org/10.1136/bmj.n1248.

Tot, I.A., Bajčetić, J.B., Jovanović, B.Ž., Trikoš, M.B., Bogićević, D.Lj. & Gajić, T.M., 2021. Biometric standards and methods. *Vojnotehnički glasnik/Military Technical Courier*, 69(4), pp.963-977. Available at: https://doi.org/10.5937/vojtehg69-32296.

Tot, I., Trikoš, M., Bajčetić, J., Lalović, K. & Bogićević, D. 2021b. Software platform for learning about brain wave acquisition and analysis. *Acta Polytechnica Hungarica*, 18(3), pp.147-162. Available at: https://doi.org/10.12700/APH.18.3.2021.3.8.

Vugdelija, N., Nedeljković, N., Kojić, N., Lukić, L. & Vesić, M. 2021. Review of brute-force attack and protection techniques. In: *13th International Conference, ICT Innovations 2021*, Skopje, North Macedonia, (18), pp.220-230, September 27–29 [online]. Available at: https://proceedings.ictinnovations.org/2021/paper/554/review-of-brute-force-attack-and-protection-techniques [Accessed: 20 April 2023].

Zajeganović, M., Zajić, G., Kurbalija, N., Pavlović, M. & Čabarkapa, S. 2019. Encryption types overview. In: *14th International conference on Risk and safety engineering*, Kopaonik, Serbia, pp.145-150, January 11-13 [online]. Available at: http://www.rizik.vtsns.edu.rs/wp-content/uploads/2019/03/Zbornik-RIZIK-2019.pdf (in Serbian) [Accessed: 20 April 2023]. ISBN: 978-86-6211-116-6.

Zhou, L., Bao, J., Watzlaf, V. & Parmanto, B. 2019. Barriers to and Facilitators of the Use of Mobile Health Apps From a Security Perspective: Mixed-Methods Study. *JMIR mHealth and uHealth*, 7(4), e11223. Available at: https://doi.org/10.2196/11223.

Безопасность данных в мобильном здравоохранении

Мария Б. Заеганович[а], **корреспондент**, *Наталия* Й. Вугделиа[а], *Радиша* Р. Стефанович[б], *Силва* М. Костич[а], *Урош* Д. Милькович[в], *Георг* Г. Мах[в]

[а] Белградская академия технического и художественного профессионального обучения, отделение Высшей школы информационных и коммуникационных технологий, г. Белград, Республика Сербия

[б] Белградская академия технических и профессиональных исследований, кафедра прикладных инженерных наук, г. Пожаревац, Республика Сербия

[в] Кампус ФХ Вена - Университет прикладных наук, г. Вена, Республика Австрия

РУБРИКА ГРНТИ: 20.23.25 Информационные системы с базами знаний
28.21.27 Структуры систем передачи данных
49.33.35 Надежность сетей связи и защита информации
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Цифровизация здравоохранения приобрела особое значение с момента начала пандемии COVID-19. С тех пор ее совершенствование является одной из основных целей правительства Республики Сербия. Телемедицина – отличное решение особенно для пациентов, которые не могут посещать медицинские учреждения. Мобильные медицинские приложения уже широко используются, однако в обеих областях важной проблемой является безопасность данных. Целью данной статьи является обзор технических решений для обеспечения безопасности данных в мобильном здравоохранении, а также выявление возможных проблем в процессе цифровизации системы здравоохранения в Сербии.

Методы: Данный обзор основан на современных исследованиях в этой области, на имеющейся релевантной литературе и многолетнем опыте авторов в этой области. Опыт процесса цифровизации здравоохранения в Сербии основан на имеющихся статьях и регламентах. В заключении статьи авторы обсуждают возможные вызовы на основании всех перечисленных факторов в области безопасности данных в мобильном здравоохранении.

Результаты: Анализ доступных работ с точки зрения безопасности данных показал, что пользователи часто готовы пожертвовать своей конфиденциальностью ради удобства, предоставляемого мобильными приложениями.

Выводы: На основании обзора исследований и четких требований к безопасности данных, включающих представленные меры предосторожности можно сделать вывод, что одной из основных задач всего сообщества является повышение осведомленности об информационной безопасности и понимания того, насколько кибергигиена важна для каждого человека, так как она является фундаментом безопасного использования услуг электронного здравоохранения.

Ключевые слова: информационная безопасность, электронное здравоохранение, телемедицина, мобильное здравоохранение, атаки, предотвращение атак.

Безбедност података у мобилном здравству

Марија Б. Зајегановић[а], **аутор за преписку**, *Наталија* Ј. Вугделија[а], *Радиша* Р. Стефановић[б], *Силва* М. Костић[а], *Урош* Д. Миљковић[в], *Георг* Г. Мах[в]

[а] Академија техничко-уметничких струковних студија Београд, Одсек Висока школа за информационе и комуникационе технологије, Београд, Република Србија

[б] Академија техничких струковних студија Београд, Одсек Примењене инжењерске науке, Пожаревац, Република Србија

[в] ФХ кампус Беч – Универзитет примењених наука, Беч, Аустрија

ОБЛАСТ: телекомуникације, информационе технологије
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Дигитализација здравства добила је посебан значај у време појаве корона вируса COVID-19, и постала један од примарних циљева Владе Републике Србије. Телемедицина је добро решење у случају када пацијент није у могућности да дође у здравствену установу. Мобилне апликације које се односе на здравство су увелико у употреби, али у оба случаја важан изазов је безбедност података. У раду су сагледана техничка решења која се односе на безбедност података у мобилном здравству и представљени су могући изазови у процесу дигитализације здравственог система у Србији.

Методе: Овај рад заснива се на актуелним радовима , на доступној релевантној литератури и вишегодишњем искуству аутора у овој области. Предочена су и искуства у процесу дигитализације здравства у Србији, као и могући изазови у области безбедности података у мобилном здравству.

Резултати: Анализом прегледаних радова са становишта безбедности података показано је да су корисници често спремни да жртвују своју приватност ради погодности које им пружају мобилне апликације.

Закључак: На основу прегледа радова и јасних захтева у погледу безбедности података који укључују представљене заштитне мере, један од главних задатака целокупне заједнице јесте подизање свести о безбедности информација и о потреби сајбер хигијене сваког појединца, што представља основ за безбедно коришћење услуга е-здравства.

Кључне речи: безбедност информација, е-здравство, телемедицина, мобилно здравство, напади, спречавање напада.

Paper received on / Дата получения работы / Датум пријема чланка: 22.04.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 14.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 16.06.2023.

Data-driven reliability and availability of electronic equipment

Slavko J. Pokorni
Information Technology School, Belgrade, Republic of Serbia,
e-mail: slavko.pokorni@its.edu.rs,
ORCID iD: https://orcid.org/0000-0002-3173-597X

DOI: 10.5937/vojtehg71-43474; https://doi.org/10.5937/vojtehg71-43474

FIELD: electronics
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose Reliability and availability are important especially for military, medical, and other professional equipment. Reliability and availability management and/or prognostic reliability calculations have always been data driven. This article focuses on the analysis of the data impact on reliability and availability.

Methods: This research is based mostly on the articles published by the author of this work as well as on some other papers.

Results: This paper results in a discussion on the definition of the data-driven concept, preceded by brief definitions of reliability and availability, and followed by the analysis of the main impacts of uncertain data on prognostic reliability calculations as well as by reliability and availability of data used in reliability calculations.

Conclusions: Reliability and availability are still very important. Reliability and availability have always been data driven while valid and relevant data have always been the main problem. Without good data, prognostic reliability is useless in spite of a good reliability model.

Key words: data driven, reliability, availability, data, equation.

Introduction

Reliability as theory and practice appeared after the Second World War. It was first applied to hardware, then to software and humans. Reliability is still very important nowadays (Pokorni, 2014b). Availability is connected with reliability. Reliability and availability have the same meaning for unrepairable products while availability is more important for products intended to be repaired.

NOTE: This work, under a similar title, was presented at *10th International Scientific Conference on Defensive Technologies OTEH 2022*, Belgrade, Serbia, pp.591-594, October 13-14, 2022.

We will use the term 'product' for a device, item, component, system, etc.

Reliability has always been data driven (Pokorni, 2021a, 2022). Without good data, prognostic reliability is useless in spite of a good reliability model. Therefore, input data in a reliability model and in a decision-making system in reliability management are of crucial importance. The same can be said for availability.

How to obtain good data is a big problem. Regarding relaibility, such data can be rarely obtained from producers of components or devices (electronic, mechanical) and/or software. Until the nineties of the last century, data about failure rates of electronic elements were available from the well-known military handbook MIL-HDBH-217 (Military Handbook, 1986). However, the latest version of this handbook is from 1995, so these data are obsolete (Pokorni, 2014b). Since these data are statistical, reliability (i.e., probability) which is calculated based on these data is valid only with a certain probability. Some data can be used from other sources but they are usually not up to date either.

Therefore, there is a question: to calculate reliability or not to calculate it? From this author's experience (of almost 30 years of teaching (talking to students that input data is the biggest problem in reliability calculations) and 40 years of practice in reliability calculations of electronic equipment) it is better to do calculations even based on obsolete data, especially at the beginning of designing a device or a system, because this can help to chose a better solution (alternative) from the point of view of reliability.

Of course, when it is necessary to decide whether such devices, software or systems satisfy certain reliability requirements, obsolete or uncertain data should not be relied upon.

In (Pokorni, 2021b), it is concluded that the problem is how to cope with large amounts of data on the one hand, and with very small amounts of data on the other hand. Both of these can be the case in reliability and maintenance, and more often there is a problem of not enough data or no data at all.

Firstly, the definition of the data-driven concept is given preceded by short definitions of reliability and availability, and after that the impact of uncertain data on prognostic reliability calculations is discussed as well as reliability and availability of data. So, we speak about the availability of a product, and the availability of the data for this product.

Before analysing the impact of data on reliability and availability, we will give a brief definition of reliability and availability.

Definition of reliability

It is enough for this paper to say that reliability is the probability that a device will meet the intended standards of performance and deliver the desired results within a specified period of time under specified (environmental) conditions (Pokorni, 2021a).

Reliability is very important not only in military and professional products. Reliability nowadays also plays a crucial role in safety and adoption of driverless cars.

Definition of availability

Availability is the probability whether the product is ready to perform its function when it is required (Pokorni, 2014a). Availability can be defined in different ways. It is generally defined as (Pokorni, 2014a):

$$G = \frac{t_{op}}{t_{op} + t_d} \qquad (1)$$

where t_{op} , and t_d are the operational time and the down time of a product, respectively.

This is usually called operational availability. If the operational time and the down time of a product are recorded, availability can be calculated. So with carefully recording such data, it is possible to obtain data about availability. It is not easy to get data about reliability.

Calculating availability is important. If there is a so-called Service Level Agreement (SLA), then it must be possible to calculate availability in order to see if that SLA is fulfilled.

Definition of the term 'data driven'

Being data-driven means that all decisions and processes are based on data. This is most evident in the field of big data (Pokorni, 2021a; Rouse, 2018). It is in connection with data science, data mining, etc. The term data-driven is used in many fields, in reliability as well.

Being based on data means using data, and using data means at least collecting and analysing data. This implies using some kind of communication. To achieve this, technology products (different devices, networks, software, Internet of Things, etc.) are used and anything of these can fail. Of course, it is advisable to avoid failures and resolve them if they happen, and this is the task of reliability.

Data-driven as a term describes a decision-making process which involves collecting data, extracting patterns and facts from these data, and utilizing these facts to draw inferences that influence decision making (Northeastern University, 2019).

Making decisions is a fundamental component of business and personal management. Good decisions lead to success while poor decisions lead to loss or failure. And this depends on data.

Every organisation today aims to be data driven. Data-driven decision making is the process of making organizational decisions based on actual data rather than on intuition or observations alone. This is the case in reliability as well (Northeastern University, 2019).

Impact of data on reliability and availability

As stated before, reliability has always been data driven (if being data driven means that all decisions and processes are based on data), while valid and relevant data have always been the main problem. It is important if some data are historical (from past experiences on failures) or gathered from new devices for which we calculate reliability. Of course, data gathered from new devices for which we calculate reliability are more valuable than data from past experiences, because data from the past come from different devices and older components, if data are used from handbooks, for example MIL-HDBK 217. Data about failure rates of new components are rarely available from producers.

In Military Handbook 217E (1986), it is stated that "Considerable effort is required to generate sufficient data on a part class to report a statistically valid reliability figure for that class. Casual data gathering on a part class occasionally accumulates data more slowly than the advance of technology in that class; consequently, a valid level of data is never attained.“

In Military Handbook 217F (1991), it is stated that “The first limitation is that the failure rate models are point estimates which are based on available data.”

Obviously, there are problems to gather sufficient and good data, in spite of the amount of effort taken. The problem is not only insufficient data, but also the accuracy of such data.

We will discuss the impact of data on reliability from several aspects: accuracy, availability, up-to-dateness of data, experience, culture in organisation, etc. Data are also the basis for reliability test developing.

Accuracy of data

Reliability calculation (or better to say estimation) is always predictive (prognostic) i.e., it predicts what will happen in the future, for example what is a probability that a device will not fail after a certain time of operation. First let us see how an error or accuracy in input data in a simple reliability model (a reliability block diagram, RBD) can affect results for prognostic reliability calculations. In a so-called Parts Count reliability calculation which is implemented in MIL-HDBH-217, a serial configuration RBD model is used (Figure 1) (Pokorni, 2014a).

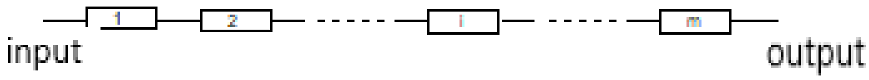


Figure 1 – Serial RBD model
Рис. 1 – Последовательная модель структурной надежности
Слика 1 – Редни структурни модел поузданости

Figure 2 shows the reliability of the serial RBD model R_s as a function of the reliability of an element (all elements are with the same reliability R) and the number of these elements m. From Fig. 2, it can be seen that an error in the input data (if we consider the difference in R as an error in the input data) for the reliability of one element has a bigger impact on the reliability when a system has more components, which is usually the case. For example, if a serial RBD has 5 elements, and the reliability of each element is R=0.8, then an error of ±12.5 (it means that we used R=0.9 and R=0.7) will produce an error in the reliability of the system R_s of + 80% and – 48.7%. It can be seen from Fig. 2 that errors depend on the reliability of elements R and the number of elements m, i.e., errors are smaller if the number of elements is smaller.

Figure 3 shows a parallel RBD model of a system. Fig. 4 shows the reliability of a parallel RBD model as a function of the reliability of an element (all elements are with the same reliability) and the number of these elements n. From Fig. 4, it can be seen that an error in the input data for one element has a smaller impact on reliability when a system has more components, but in this case such a system is more costly. Adding the second element with the mean time to failure (MTTF) will increase the mean time to failure of the system ($MTTF_S$) for 50%, adding the third element results in 33% increase, and adding the fourth element leads to 25% increase, as obvious from the equation (Pokorni, 2014)

$$MTTF_s = MTTF\left(1+\frac{1}{2}+\ldots+\frac{1}{n}\right) \tag{2}$$

So, adding more elements in parallel to increase reliability will increase rather cost than reliability. Reliability and cost are mutually dependent. Higher reliability means higher cost, but cost for maintenance will be lower.

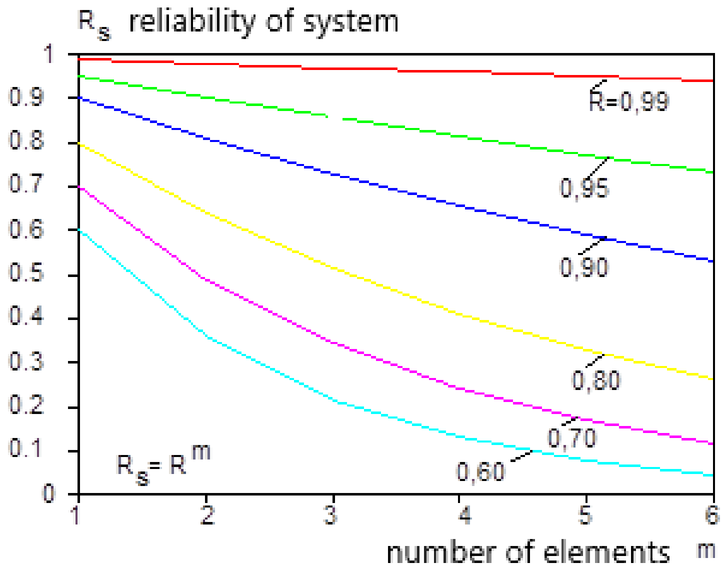


Figure 2 – Reliability of a serial RBD model
Рис. 2 – Надежность последовательной модели структурной надежности
Слика 2 – Поузданост редног структурног модела поузданости

Availability of data

Availability of good data is a very big problem, especially today when technology changes very fast, and some components are very reliable (but we do not know to what extent) and we do not have timely and accurate data about their failure rates, i.e., reliability. As mentioned before, military handbooks (e.g. MIL-HDBK-217) can be used (but such data are obsolete), as well as commercial handbooks, data from producers (but these data are rarely available), or one's own data (which are not often available either).

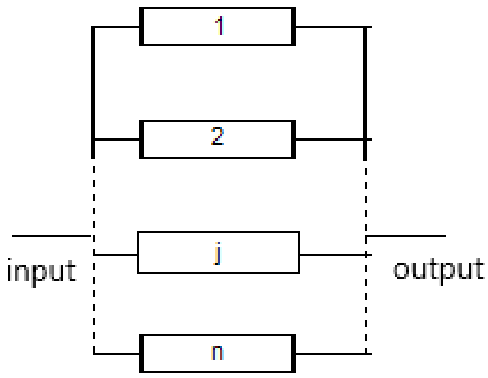


Figure 3 – Parallel RBD model
Рис. 3 – Параллельная модель структурной надежности
Слика 3 – Паралелни структурни модел поузданости

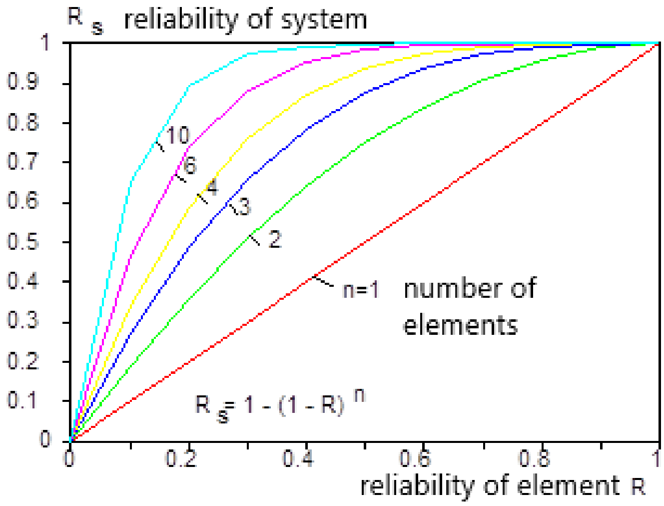


Figure 4 – Reliability of a parallel RBD model
Рис. 4 – Надежность параллельной модели структурной надежности
Слика 4 – Поузданост паралелног структурног модела поузданости

Experience in the calculation of reliability

The experience of this author has shown that the calculated prognostic MTBF of electronic equipment, using MIL-HDBK-217, should be at least or about twice of the required MTBF in order to have operational (actual, correct) MTBF equal to the required (original) MTBF and that was applied as a rule when the Parts Count reliability calculation was made (Pokorni, 2014b).

The author is not the only one who had the problem of inadequate input data of electronic elements and inadequate estimation of these input data in the calculation of reliability (Pokorni, 2014b).

Another problem with data is that when there is a small number of produced devices, there are not not enough data.

Devices with very high required reliability present additional chalenges: in this case, real data are obtained only after a long time after these devices come into use.

One solution to the problem when there is not enough relevant data is seen in the so-called Physics of Failure, but it is applicable in the wear area of a failure rate. However, in the Physics of Failure, there is again a problem not only with relevant data but also with the knowledge of different processes in component materials (Pokorni, 2014a).

Besides input data in reliability calculation models, data from reliability analyses of systems or devices can offer more information. For example, in (Pandian et al, 2020), the Boeing 787 Dreamliner reliability was analysed using a data-driven approach. From various documents and trends, it was concluded that Boeing did not adopt an effective Reliability Program Plan where the best practice tasks are implemented to produce reliable products. Boeing opted to widen its supplier base and reduce costs by including manufacturers who were new to the aircraft development industry. The events that led to delays during manufacturing and failures during operation are a testament to Boeing's flawed practices.

Boeing's flawed practices that can serve as valuable lessons were as follows:

Short development cycle and highly complex supply chains,
Lack of accurate and timely information sharing,
Lack of relevant data,
Lack of valid testing on innovative technologies,
Difficulty in fault detection, and
Lack of balance between autonomy and oversight.

Furthermore, these deficiencies are seldom independent of each other and can have a compounding effect on product reliability.

Quality of data

Data quality is only one problem in reliability. In (Elearth & Pecht, 2012), it is stated that there is no standard method for creating hardware reliability prediction, so predictions vary widely in terms of methological rigor, data quality, extent of analysis and uncertainty while the documentation of the prediction process employed is often not presented. The IEEE thus created a standard, IEEE 1413 (Standard Framework for the Reliability Prediction of Hardware), in 2009.

Culture in an organization

Gathering good data is in connection with individual and organizational culture. The most important part of the development of a reliability program in an organization is to have a culture of reliability. It is extremely important that everyone involved in the creation of products, from the top on down, realize that a good reliability program is necessary for the success of their organization (Pokorni, 2014b, 2016).

The reliability effort produces and uses a different amount of information and data.

One possible solution when there is not enough relevant data and an analytical reliability model cannot be derived is simulation (Pokorni & Janković, 2011). An example of not such a complex problem is illustrated in (Pokorni & Ramović, 2003).

Reliability is connected with maintainability. Reliability and maintainability are important factors in the total cost of equipment. An increase in maintainability can lead to reduction in operating and support costs. For example, a more maintainable product lowers maintenance time and operating costs. Furthermore, more efficient maintenance means a faster return to operation or service, decreasing downtime (Brunton et al, 2021). Again, good and timely data are necessary.

Reliability and availability of data

Reliability of data and their availability can be discussed as well. In order to build trust in data, it is critical that they are reliable, i.e., complete and accurate.

Data reliability means that data are complete and accurate, and it is a crucial foundation for building data trust across any organization. Ensuring data reliability is one of the main objectives of data integrity initiatives, which are also used to maintain data security, data quality, and regulatory compliance (Talend, 2023; Pokorni, 2021a).

Reliability leaders need reliable data to make reliable decisions. Therefore, in data-driven reliability, data reliability is of crucial importance. Data reliability is not the same as data validity. Reliability of data is based on data validity, completeness, and uniqueness (Pokorni, 2021a).

Nowadays, in the reliability domain, there is not only lack of good data, but there is lack of any data. People dealing with reliability calculations can see that clearly.

If the Internet of Things (IoT) is used tto gather data, because of IoT unreliability, data can be missing, incomplete and/or corrupted (Pokorni, 2021a).

Data for maintainability are usualy gathered from sensors or the IoT - if these are not reliable, data can also be unreliable. Unreliable IoT can produce unreliable data as an input in a decision-making system, so decisions can be wrong.

Similar situation can happen with artificial intelligence incorporated in a decision-making system. Can artificial intelligence recognize bad data? Or will we believe in a decision made in such a way?

Reliability equation

Because a data-driven reliability system includes hardware, software, sometimes humans, and data, we suggest assessing the reliability of a data-driven reliability system by changing the equation from the (Pokorni, 2019, 2020, 2021a, 2021b) to the following one:

$$R_S(t) = R_{HW}(t) R_{SF}(t) R_H(t) R_D(t) \tag{3}$$

where R_{HW}, R_{SF}, R_H and R_D are the reliability of hardware, software, humans and data subsystems, respectively.

Conclusion

Reliability and availability continue to be very important. Reliability and availability have always been data driven while valid and relevant data have always been the main problem. Without good data, prognostic reliability is useless in spite of a good reliability model. This can be the case with maintainability as well.

In reliability calculations, there is usually a bigger problem with not enough relevant data than with large amounts of data. The problem is not only insufficient data, but also the (in)accuracy of data.

In reliability calculations, the data from MIL-HDBK-217 are usually used, and these are data from the past, obsolete in most cases. Up-to-date data of failure rates of elements are rarely available. Regarding availability, it is a matter of accurately recording data about the operational time and the down time of a product being used.

References

Brunton, S.L., Kutz, J. N., Manohar, K., Aravkin, A.Y., Morgansen, K., Klemisch, J., Goebel, N., Buttrick, J., Poskin, J., Blom-Schieber, A.W., Hogan, T. & McDonald, D. 2021. *AIAA Journal*, 59(8). Available at: https://doi.org/10.2514/1.J060131.

Elearth, J.G. & Pecht, M. 2012. IEEE 1413: A Standard for Reliability Predictions. *IEEE Transactions on Reliability,* 61(1), pp.125-129. Available at: https://doi.org/10.1109/TR.2011.2172030.

-Military Handbook, MIL-HDBK-217E. 1986. *Reliability Prediction of Electronic Equipment*. Washington DC: Department of Defense.

-Military Handbook, MIL-HDBK-217F. 1991. *Reliability Prediction of Electronic Equipment*. Washington DC: Department of Defense.

-Northeastern University. 2019. Data-Driven Decision Making: A Primer for Beginners. *Northeastern University*, August 22 [online]. Available at: https://www.northeastern.edu/graduate/blog/data-driven-decision-making/ [Accessed: 15 March 2023].

Pandian, G., Pecht, M., Zio, E. & Hodkiewicz. M. 2020. Data-driven reliability analysis of Boeing 787 Dreamliner. *Chinese Journal of Aeronautics*, 33(7), pp. 1969-1979. Available at: https://doi.org/10.1016/j.cja.2020.02.003.

Pokorni, S. 2014a. *Pouzdanost informacionih sistema*. Belgrade, Serbia: Information Technology School (in Serbian). ISBN: 978-86-88841-03-0.

Pokorni, S. 2014b. Problems of reliability prediction of electronic equipment. In: *6th International Scientific Conference on Defensive Technologies OTEH 2014*, Belgrade, Serbia, pp.835-838, October 9-10 [online]. Available at: http://www.vti.mod.gov.rs/oteh14/elementi/rad/028.html [Accessed: 15 March 2023].

Pokorni, S. 2016. Reliability prediction of electronic equipment: Problems and experience. In: *7th International Scientific Conference on Defensive Technologies OTEH 2016*, Belgrade, Serbia, pp.695-700, October 6-7 [online]. Available at: http://www.vti.mod.gov.rs/oteh16/elementi/rad/020.html [Accessed: 15 March 2023].

Pokorni, S. 2019. Reliability and availability of the Internet of things. *Vojnotehnički glasnik/Military Technical Courier*, 67(3), pp.588-600. Available at: https://doi.org/10.5937/vojtehg67-21363.

Pokorni, S. 2020. Artificial intelligence in reliability and maintainability. In: *9th International Scientific Conference on Defensive Technologies OTEH 2020*, Belgrade, Serbia, October 15-16 [online]. Available at: http://www.vti.mod.gov.rs/oteh/elementi/rad/114.pdf [Accessed: 15 March 2023].

Pokorni, S. 2021a. The Reliability of Data-driven Internet of Things Systems. *Annals of Spiru Haret University. Economic Series*, 21(4), pp.43-52 [online]. Available at: http://anale.spiruharet.ro/economics/issue/view/137/pdf_25 [Accessed: 15 March 2023].

Pokorni, S. 2021b Current state of the application of artificial intelligence in reliability and maintenance. *Vojnotehnički glasnik/Military Technical Courier*, 69(3), pp.578-593. Available at: https://doi.org/10.5937/vojtehg69-30434.

Pokorni, S. 2022. Data-driven reliability of electronic equipment. In: *10th International Scientific Conference on Defensive Technologies OTEH 2022,* Belgrade, Serbia, pp.591-594, October 13-14 [online]. Available at: http://www.vti.mod.gov.rs/oteh/elementi/rad/043.pdf [Accessed: 15 March 2023].

Pokorni, S. & Janković. R. 2011. Reliability estimation of a complex communication network by simulation. In: *2011 19thTelecommunications Forum (TELFOR) Proceedings of Papers,* Belgrade, Serbia, pp.226-229, November 22-24. Available at: https://doi.org/10.1109/TELFOR.2011.6143532.

Pokorni, S. & Ramović, R. 2003. Reliability and availability of telecommunication system of four ring connected stations. *Communications in Dependability and Quality Management,* 6(1-2), pp.6-17. ISSN: 1450-7196.

Rouse, M. 2018. What Does Data Driven Mean? *Techopedia*, 9 February [online]. Available at https://www.techopedia.com/definition/18687/data-driven [Accessed: 15 March 2023].

-Talend. 2023. What is data reliability? Definition and assessment guide. *Talend* [online]. Available at https://www.talend.com/resources/what-is-data-reliability/ [Accessed: 15 March 2023].

Надежность и доступность электронного оборудования, основанные на управлении данными

Славко Й. Покорни

Колледж информационных технологий, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 78.21.49 Военная электроника и кибернетика
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Надежность и доступность представляют особое значение для военного, медицинского и прочего профессионального оборудования. Управление надежностью и доступностью и/или расчеты прогнозирования надежности всегда основывались на данных. Данное исследование посвящено анализу влияния данных на надежность и доступность.

Методы: Настоящее исследование основано на опубликованных работах автора данной статьи, а также на исследованиях других авторов.

Результаты: Результатами данного исследования являются: во первых, обсуждение определения подхода к управлению данными (data-driven), во-вторых, определение надежности и доступности, в-третьих, выявление влияния недостаточно надежных данных на *расчет прогностической надежности, а также на надежность и доступность данных, используемых при расчете надежности.*

Выводы: Надежность и доступность по-прежнему очень важны. Надежность и доступность всегда зависили от управления данными, а достоверные и актуальные данные всегда вызывали серьезную озабоченность. Прогностическая надежность без соответствующих данных будет бесполезной, даже если модель надежности безупречна.

Ключевые слова: управление данными (data-driven), надежность, доступность, данные, формула.

Поузданост и расположивост електронских система вођени подацима

Славко J. Покорни

Висока школа струковних студија за информационе технологије, Београд, Република Србија

ОБЛАСТ: електроника
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Поузданост и расположивост су посебно важни за војну, медицинску и другу професионалну опрему. Управљање поузданошћу и расположивошћу и/или прорачун прогностичке поузданости увек су били засновани на подацима. У истраживању се анализира утицај података на поузданост и готовост.

Методе: Истраживање је рађено углавном на основу објављених чланака аутора овог рада, као и неких других радова.

Резултати: Анализиране су дефиниције концепта вођеног подацима, затим дефиниција поузданости и расположивости, а након тога утицај недовољно поузданих података на прорачун прогностичке поузданости, као и поузданост и расположивост података који се користе у прорачуну поузданости.

Закључак: Поузданост и расположивост, као веома важни, увек су били вођени подацима, али валидни и релевантни подаци представљају главни проблем. Без добрих података прогностичка поузданост је бескорисна, упркос добром моделу поузданости.

Кључне речи: вођено подацима, поузданост, расположивост, подаци, формула.

Paper received on / Дата получения работы / Датум пријема чланка: 17.03.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 13.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 15.06.2023.

Formation and application of hydrogen in non-ferrous metallurgy

Srećko R. Stopić[a], *Bernd* G. Friedrich[b]

RWTH Aachen University, IME Process Metallurgy and Metal Recycling, Aachen, Federal Republic of Germany

[a] e-mail: sstopic@ime-aachen.de, **corresponding author**, ORCID iD: https://orcid.org/0000-0002-1752-5378

[b] e-mail: bfriedrich@ime-aachen.de, ORCID iD: https://orcid.org/0000-0002-2934-2034

DOI: 10.5937/vojtehg71-43407; https://doi.org/10.5937/vojtehg71-43407

FIELD: chemical technology
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose: Hydrogen is the most abundant element in the universe (75 % by mass) and the lightest element (with a density of 0.00082 g/cm^3) which consists of only one proton and one electron. Because of its presence in many different forms such as gaseous hydrogen, its plasma species, water, acid, alkalline, ammmonia and hydrocarbons, it has various applications in different industrial disciplines.

Methods: Different hydrometallurgical and pyrometallurgical methods are considered in order to point out many different processes such as formation of hydrogen, reduction of metallic oxides and chlorides, and electrochemical reactions such as hydrogen overvoltage and the spillover effect. Ultrasonic spray pyrolysis enables the formation of very fine aerosols which can be used for the production of metallic powders.

Results: Hydrogen formation was observed during the dissolution of metallic allloys with hydrochloric acid. The reduction of metallic oxides and metallic chlorides by hydrogen leads to the formation of metallic powders. Metallic powders were collected by a new developed electrostatic precipitator.

Conclusion: Hydrogen can be applied in different reduction processes for the production of metallic powders. Recycling processes can be used for the formation of hydrogen. A new research strategy for powder production is proposed combining recycling of the black mass of used Li-Ion batteries, ultrasonic spray pyrolysis, and hydrogen reduction.

Key words: hydrogen, reduction, formation, acid, recycling, electrostatic precipitator.

Introduction

Hydrogen as the key element in energy transition replacing fossil fuels and their CO_2 emissions was used as a reducing agent instead of carbon thus attracting strong interest in hydrometallurgy and pyrometallurgy of non-ferrous metals (Stopić et al, 1997b). Control of hydrogen formation during hydrometallurgical processes such as electrocoagulation and winning electroysis has a high significance for metal recovery (Rodriguez et al, 2007b)

During sulphuric acid pressure leaching of copper oxidic ores containing silicates, the leaching solution contains copper sulfate with a low concentration of copper (approx. 5-10 g/L). After solvent extraction, the concentration of copper is increased until 30-40 g/l. Copper formation is possible by using hydrogen reduction in an autoclave under increased temperature (Hage et al, 1999). One version of this reduction process is gaseous reduction where metals are precipitated from leach solutions by direct contacting with reducing gases such as hydrogen and carbon monoxide. For the same fuel consumption, hydrogen reduction has the potential to produce two to six times as much metal as the competing traditional electrowinning process (Sista & Sliepcevich, 1981). To date, gaseous reduction has been practiced commercially primarily in batch operations or in semi-continuous, stirred autoclaves and tubular reactors. Under high pressure and temperature conditions, hydrogen reduction of aqueous copper sulfate in a continuous flow tubular reactor requires strict control of both feed temperature precipitation of basic copper sulfate and inlet pH-values (about pH-Value of 1.8) to prevent the formation of cuprous oxide during reduction. A bench scale investigation on the hydrogen reduction of a highly acidic copper bleed solution was performed in a titanium lined autoclave of 1 L. A producing 99% copper powder recovery which was reached at a pressure of about 2400 kPa, a reaction temperature of 453 K, and a stirring speed of 400 rpm for a reaction time of 2 h (Agrawal et al, 2006).

Similarly to copper production, an alternative process to electrowinning for the recovery of nickel from purified nickel solutions is hydrogen reduction under high pressure and high temperature conditions (Crundwell et al, 2011). Hydrogen reduction is carried out by injecting hydrogen into aqueous ammoniacal nickel sulfate solutions in stirred high-pressure autoclaves. The following steps are performed: the preparation of nickel ‘seed’ powder; the reduction of solution batches; the finishing of a 50 tonne “lot” of nickel powder; and the preparation of the autoclave for a new cycle.

This literature review aims at advances in understanding the role of hydrogen in non-ferrous metallurgy. The formation of hydrogen and its application for the synthesis of metallic powder will be explained in this study.

Hydrogen formation in hydrometallurgical processes

The formation of hydrogen was presented in zinc winning electrolysis, the treatment of wastewater with copper electrolysis, and in the treatment of black mass for recycling used Li-Ion batteries.

Zinc winning electrolysis

The formation of hydrogen in zinc winning electrolysis was performed in an electrolytic cell from the water solution of zinc sulfate, as shown in Figure 1.

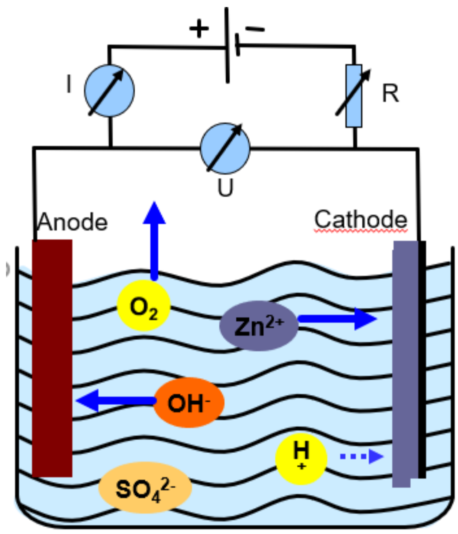


Figure 1 – Electrolytic cell
Рис. 1 – Электролизная ячейка
Слика 1 – Ћелија за електролизу

The formation of hydrogen is described via the following chemical reactions:

At the cathode:

$$Zn^{2+} + 2e^- \rightarrow Zn^0 \qquad (1)$$

At the anode:

$$H_2O \rightarrow {}^{1}/_{2}\, O_2 + 2\, H^+ + 2e^- \qquad (2)$$

Under the standard conditions, hydrogen is more noble than zinc and therefore zinc cannot be precipitated in the electrolysis of aqueous solutions. Every electrochemical reaction is inhibited in a different way for hydrogen, as shown in Figure 2.

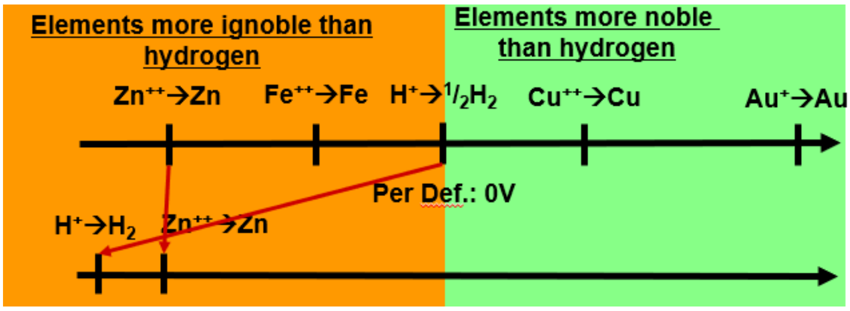


Figure 2 – Hydrogen overvoltage in zinc winning electrolysis
Рис. 2 – Перенапряжение водорода при получении цинка электролизом
Слика 2 – Пренапетост водоника у добијању цинка електролизом

The movement of the potential is enabled through the choice of different parameters: concentration of sulfuric acid, electrolyte temperature in an electrolytic cell, current density, and concentration of zinc in an acidic solution. Therefore, hydrogen overvoltage (potential difference that can be found between an electrode and a reversible hydrogen electrode within a single solution) leads to zinc precipitation as shown in Figure 2. Hydrogen is formed at an increased temperature of electrolytes (60°C), smaller concentration of zinc in an acidic solution, smaller current density and in the presence of iron and copper ions (catalytic effects). The analysis of the mechanism and kinetics of the hydrogen evolution reaction has confirmed that the hydrogen evolution reaction (HER) is the simplest electrocatalytic reaction (Lacia, 2019). With the development of renewable energy sources, electrolytic production of hydrogen becomes an alternative way of hydrogen production for internal combustion engines and fuel cells.

Electrocoagulation method for hydrogen formation

Electrocoagulation (EC) is an old electrochemical technique for treating polluted water using electricity instead of expensive chemical reagents such as sodium hydroxide needed for a chemical precipitation. EC was firstly proposed in London in 1889, where a sewage treatment plant was built and an electrochemical treatment was used via mixing domestic wastewater with saline. In the United States, J.T. Harries patented a wastewater treatment by electrolysis using sacrificial aluminium and iron anodes in 1909. Electrocoagulation (EC) may be a potential answer to environmental problems dealing with water reuse, hydrogen production, and rational waste management. The Integrated Treatment of Industrial Wastes towards Prevention of Regional Water Resources Contamination (INTREAT) Project results (2004-2006) confirmed the feasibility of the EC process for industrial contaminated effluents from Cu production, taking into consideration technical and economical factors. (Rodriguez et al, 2007a). The EC-reactor uses electrodes from aluminium and iron. This EC-reactor is connected with the control unit as shown in Figure 3.

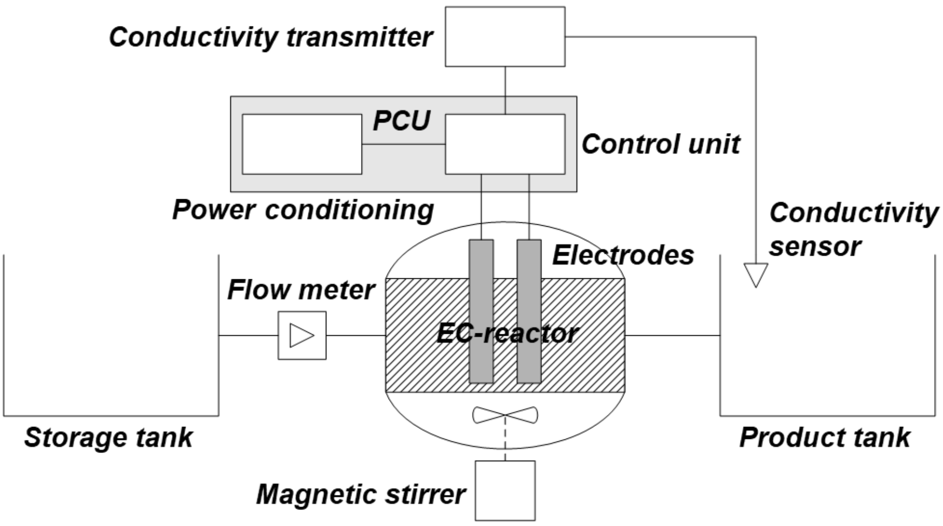


Figure 3 – Experimental setup for wastewater treatment by the EC-process
Рис. 3 – Экспериментальная установка для очистки сточных вод методом электрокоагуляции.
Слика 3 – Апаратура коришћена за пречишћавање отпадних вода процесом електрокоагулације

This EC-equipment enables the wastewater treatment and measurement of removed metals as well as the analysis of the concentration of the formed hydrogen.

As a working hypothesis, $Al^{3+(}$aq) ions are formed in the first step (Eq. 3).

$$Al(s) + 6H_2O \rightarrow Al(H_2O)_6^{3+} + 3e^- \quad (3)$$

At the cathode, hydrogen is evolved with the formation of OH^- (Eq. 4) thus raising the pH of the solution.

$$2H_2O + 2\ e^- \rightarrow 2\ OH^- + H_2 \quad (4)$$

This leads to the hydrolysis and condensation of $Al(H_2O)_6^{3+}$ in a stepwise fashion (Eq. 5) through $Al_2(OH)_2(H_2O)_8^{\ 4+}$ leading finally to an amorphous insoluble polymeric hydroxide $[Al(OH)_3]n \cdot (H_2O)_x$

$$2\ Al(H_2O)_6^{3+} \rightarrow Al_2(OH)_2(H_2O)_8^{4+} + 2\ H_3O^+ \quad (5)$$

Hydrogen was formed during the decomposition of water and the transformation of complex aluminium hydroxide complexes to hydrogen ions.

Recycling the black mass from used Li-Ion batteries

Today, the production of Li-ion batteries is widely considered to be crucial technology since it can help decarbonize transport and increase the penetration levels of intermittent renewable energy sources.

Because of high demands, used lithium-ion batteries from different sources and chemistries (lithium cobalt oxide – LCO, and lithium nickel manganese cobalt oxide – NMC) were used after a vacuum chamber treatment, mechanical and thermal treatment by pyrolysis in the nitrogen atmosphere.

After that, thermally treated cells were submitted to shredding and magnetic separation to remove the steel casing from the cells and the Fe-rich fraction (Vieceli et al, 2023).

Subsequently, the black mass was sieved at 1 mm. The fraction rich in Al and Cu foils was removed in the coarse fraction (>1 mm) and the black mass was used for leaching with hydrochloric acid.

The main components of the black mass are graphite, mixed alloys (MnNi,MnNiCu and CoNi), oxides (CoO, NiO, $LiMnNiO_2$, $LiCoO_2$; $Mn_{0.8}Fe_{0.2}O_2$), carbonates (Li_2CO_3), fluorides (LiF), and phosphates ($LiCo(PO_4)_2$).

The leaching concentration of 4 mol/L was used in 100 L reactors (as shown in Figure 4), using a solid/liquid ratio of 0.3, at an atmospheric pressure, and at temperatures below 100°C.

The chemical composition of the black mass is shown in Table 1.

Table 1 – Chemical composition of the black mass from used Li-Ion batteries
Таблица 1 – Химический состав черной массы из использованных литий-ионных аккумуляторов
Табела 1 – Хемијски састав „црног праха" из отпадне Li-Ion батерије

Element	C	Li	Co	Mn	Fe	Cu	Ni	Al	total
(%)	31.5	3.42	15.5	9.24	0.74	7.92	6.73	5.00	79,85

Hydrogen was formed using the following reactions:

$$MnNi + 4\,HCl = MnCl_2 + NiCl_2 + 2\,H_2 \quad (6)$$

$$CoNi + 4\,HCl = CoCl_2 + NiCl_2 + 2\,H_2 \quad (7)$$

$$MnNiCu + 6\,HCl = CuCl_2 + NiCl_2 + MnCl_2 + 3\,H_2 \quad (8)$$

During this treatment of the black mass with hydrochloric acid, very hazardous hydrogen fluoride was formed:

$$LiF + HCl = HF + LiCl \quad (9)$$

Figure 4 –Reactors for the dissolution of the black mass from used Li-ion batteries
Рис. 4 – Реакторы для переработки черной массы из использованных литий-ионных аккумуляторов
Слика 4 – Реактори за растварање црне масе из отпадних Li-ion батерија

The formed hydrogen was observed in the reactors and its concentration measured using TESTO-devices for the gas analysis.

Application of hydrogen in the production of metallic powders

The application of gaseous hydrogen for the reduction of metallic oxides and metallic chlorides, in comparison to alternative reducing agents such as carbon and carbon monoxide, has some advantages, as shown with equations:

$$MeO + H_2 = Me + H_2O \quad (10)$$

$$MeO + C = Me + CO \quad (11)$$

$$MeO + CO = Me + CO_2 \quad (12)$$

$$MeCl_2 + H_2 = Me + 2\ HCl \quad (13)$$

$$2MeCl_2 + 2\ C = 2\ Me + CCl4 \quad (13)$$

The advantages of hydrogen as a reducing agent:

1. Formation of water instead of carbon monoxide and carbon dioxide through the reduction of metallic oxides,
2. Formation of an acid instead of hazardous carbon tetrachloride through a reduction of metallic chloride, and
3. Environmentally friendly process.

Hydrogen is used to be not only a source of clean fuel energy, but also a reducing agent for metals production in the current industrial decarbonization effort. Hydrogen is only commercially utilized in the production of a limited number of refractory metals (i.e., W, Mo) and partly utilized in Ni and Co metals production. An improvement of hydrogen reduction was obtained using the hydrogen spillover effect. The hydrogen spillover effect (HSPE) is the most important interfacial phenomenon in which active hydrogen atoms generated via the dissociation of H_2 on one phase (metal surface) migrate to other phases (support surface) and participate in the catalytic reaction of the substance adsorbed on that site (Shen et al, 2022).

The hydrogen spillover effect was confirmed for hydrogen reduction of nickel chloride and nickel oxides in the presence of palladium, copper and nickel (Stopić et al, 1997a). Hydrogen is mostly used for the synthesis of metallic powders from water solutions of metallic nitrates and metallic chloride by ultrasonic spray pyrolysis and subsequent hydrogen reduction (Gürmen et al, 2009). The equipment for the synthesis of metallic powder contains an ultrasonic generator, a furnace and an electrostatic precipitator, as shown in Figure 5.

Figure 5 – Ultrasonic spray pyrolysis equipment
Рис. 5 – Устройство для пиролиза ультразвуковым распылением
Слика 5 – Апаратура за распршивање водених раствора у ултразвучном пољу

Hydrogen is mostly used with argon in order to prevent the formation of an explosive mixture and to avoid the formation of ammonia. Concerning the applied flow rate of hydrogen and argon, the production rate amounts to about 5g of metal per one hour in laboratory conditions.

Metallic powder was usually collected with a wet scrubber or an electrostatic filter. The newest developed electrostatic precipitator by PRIZMA, Kragujevac, is shown in Figure 6.

Figure 6 – Electrostatic precipitator for collecting powder developed by PRIZMA, Kragujevac, Serbia
Рис. 6 – Электрофильтр для извлечения порошка, разработанный компанией PRIZMA, Крагуевац, Сербия
Слика 6 – Електростатички преципитатор за сакупљање прахова развијен у компанији „Призма", Крагујевац, Србија

A new electrostatic precipitator uses a rotating electrode enabling the collection of powders avoiding condensation until 300°C.

Conclusion

Hydrogen is mostly formed during the zinc winning electrolysis, the electrocoagulation process, and through the recycling process using acid dissolving metallic alloys. The formed hydrogen is measured and stored in metallic powders such as LaNi5 in order to be used for the reduction process. As a favorable reducing agent in comparison to carbon and carbon monoxide, hydrogen is used for the formation of metallic powders. The ultrasonic spray pyrolysis of the water sollution of metallic chlorides and metallic nitrates, with subsequent hydrogen reduction, produces submicron and nanosized powders. The combined strategy of hydrogen formation and its application is shown in Figure 7.

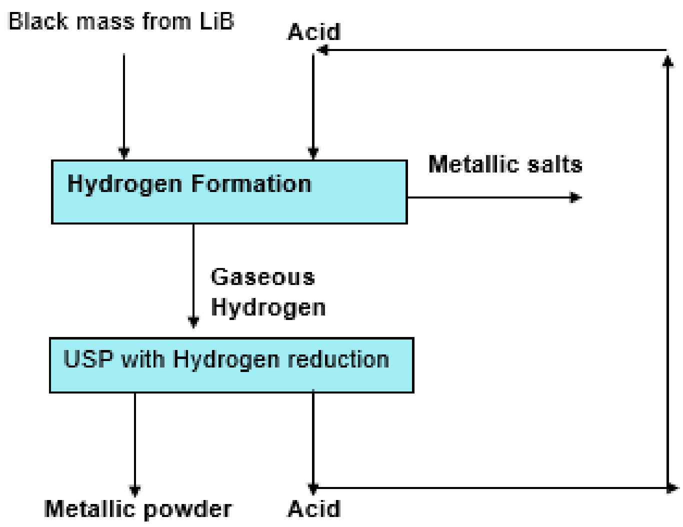


Figure 7 – Formation of gaseous hydrogen and its application
Рис. 7 – Образование газообразного водорода и его применение
Слика 7 – Формирање гасовитог водоника и његова примена

As shown in this figure, it is possible to recycle used acid and return it to the dissolution of black mass, which is an innovative route.

References

Agrawal, A., Kumari, S., Bagchi, D., Kumar, V. & Pandey, B.D. 2006. Hydrogen reduction of copper bleed solution from an Indian copper smelter for producing high purity copper powders. *Hydrometallurgy*, 84(3-4), pp.218-224. Available at: https://doi.org/10.1016/j.hydromet.2006.05.010.

Crundwell, F.K., Moats, M.S., Ramachandran, V., Robinson, T.G. & Davenport, W.G. 2011. Chapter 27 - Hydrogen Reduction of Nickel from Ammoniacal Sulfate Solutions. In*: Extractive Metallurgy of Nickel, Cobalt and Platinum Group Metals*, pp.347-354. Elsevier. Available at: https://doi.org/10.1016/B978-0-08-096809-4.10027-9.

Gürmen, S., Güven. A., Ebin, B., Stopić, S. & Friedrich, B. 2009. Synthesis of nanocrystalline spherical cobalt-iron (Co-Fe) alloy particles by ultrasonic spray pyrolysis and hydrogen reduction. *Journal of Alloys and Compounds*, 481(1-2), pp.600-604. Available at: https://doi.org/10.1016/j.jallcom.2009.03.046.

Hage, J.L.T., Reuter, M.A., Schuiling, R.D. & Ramtahalsing, I.S. 1999. Reduction of copper with cellulose in an autoclave; an alternative to electrolysis? *Minerals Engineering*, 12(4), pp.393-404. Available at: https://doi.org/10.1016/S0892-6875(99)00019-9.

Lasia, A. 2019. Mechanism and kinetics of the hydrogen evolution reaction. *International Journal Hydrogen Energy,* 44(36), pp.19484-19518. Available at: https://doi.org/10.1016/j.ijhydene.2019.05.183.

Rodriguez, J., Stopić, S. & Friedrich, B. 2007a. Continuous electrocoagulation treatment of wastewater from copper production. *World of Metallurgy - ERZMETALL*, 60(2), pp.89-95. ISSN: 1613-2394.

Rodriguez, J., Stopić, S., Krause, G. & Friedrich, B. 2007b. Feasibility assessment of electrocoagulation towards a new sustainable wastewater treatment. *Environmental Science and Pollution Research - International*, 14(7), pp.477-482. Available at: https://doi.org/10.1065/espr2007.05.424.

Shen, H., Li, H., Yang, Z. & Li, C. 2022. Magic of hydrogen spillover: Understanding and application. *Green Energy & Environment*, 7(6), pp.1161-1198. Available at: https://doi.org/10.1016/j.gee.2022.01.013.

Sista, K.M. & Sliepcevich, C.M. 1981. Kinetics of continuous hydrogen reduction of copper from a sulfate solution. *Metallurgical Transactions B*, 12, pp.565-568. Available at: https://doi.org/10.1007/BF02654328.

Stopić, S.R., Ilić, I.B., Nedeljković, J.M., Rakočević, Z.L.J., Šušić, M.V. & Uskoković, D.P. 1997a. Influence of hydrogen spillover effect on the properties of Ni particles prepared by ultrasonic spray pyrolysis. *Studies in Surface Science and Catalysis*, 112, pp.103-110. Available at: https://doi.org/10.1016/S0167-2991(97)80828-2.

Stopić, S.R., Ilić, I.B. & Uskoković, D.P. 1997b. Effect of Pd, Cu, and Ni additions on the kinetics of NiCl2 reduction by hydrogen. *Metallurgical and Materials Transactions B*, 28, pp.1241-1248. Available at: https://doi.org/10.1007/s11663-997-0079-2.

Vieceli, N., Vonderstein, C., Swiontek, T., Stopić, S., Dertmann, C., Sojka. R., Reinhardt, N., Ekberg, C., Friedrich, B. & Petranikova, M. 2023. Recycling of Li-Ion Batteries from Industrial Processing: Upscaled Hydrometallurgical Treatment and Recovery of High Purity Manganese by Solvent Extraction. *Solvent Extraction and Ion Exchange*, pp.1-16. Available at: https://doi.org/10.1080/07366299.2023.2165405.

Образование и применение водорода в металлургии цветных металлов

Сречко Р. Стопич, **корреспондент**, *Бернд* Г. Фридрих

Технический университет города Ахен,
Институт металлургических процессов и рециклирования металлов,
г. Ахен, Федеративная Республика Германия

РУБРИКА ГРНТИ: 61.13.21 Химические процессы
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Водород является самым распространенным элементом во Вселенной (75 % по массе) и самым легким

элементом (с плотностью 0,00082 г/см³). Он состоит всего лишь из одного протона и одного электрона. Благодаря его содержанию во множестве различных форм, таких как газообразный водород и его плазменные разновидности, вода, кислота, щелочь, аммоний и углеводороды, он широко применяется в различных отраслях промышленности.

Методы: В статье рассматриваются различные гидрометаллургические и пирометаллургические методы с целью выявления множества различных процессов, таких как образование водорода, восстановление оксидов и хлоридов металлов, а также электрохимические реакции, такие как перенапряжение водорода и побочные эффекты. Пиролиз ультразвуковым распылением позволяет получать мельчайшие аэрозоли, которые могут быть использованы для производства металлических порошков.

Результаты: При растворении металлических сплавов соляной кислотой выявлено образование водорода. Восстановление металлов из оксидов и хлоридов водородом приводит к образованию металлических порошков. С помощью нового разработанного электрофильтра были извлечены порошки металлов.

Выводы: Процессы рециркуляции могут быть использованы в производстве водорода. В свою очередь, водород можно использовать в различных процессах восстановления в производстве металлических порошков. В статье предлагается новая исследовательская стратегия, сочетающая производство водорода в процессе переработки «черной массы» из литий-ионных аккумуляторов с ультразвуковым напылением, термическим разложением капли и восстановлением водорода.

Ключевые слова: водород, восстановление, образование, кислота, рециркуляция, электрофильтр.

Формирање и примена водоника у металургији обојених метала

Срећко Р. Стопић, **аутор за преписку**, *Бернд* Г. Фридрих

Технички универзитет у Ахену, Институт за процесну металургију и рециклирање метала, Ахен, Савезна Република Немачка

ОБЛАСТ: хемијске технологије
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Водоник је најраспрострањенији елемент универзума (75 % масених процената), као и најлакши (густина 0.00082 г/цм³)), који *се састоји од једног протона и једног електрона. Због великог присуства у различитим формама, као што су гасовити водоник, плазма-облици, вода, киселина, базе, амонијак и једињења са угљеником, водоник има високу примену у многим индустријским дисциплинама.*

Методе: Различите приометалуршке и хидрометалуршке методе размотрене су у намери да истакну много различитих процеса – формирање водоника, редукција металних оксида и хлорида, као и електрохемијске реакције, као што је пренапетост водоника. Ултразвучно распршивање са термичким разлагањем капи омогућава формирање финих аеросола, који касније могу бити коришћени за производњу металних прахова.

Резултати: Водоник је формиран растварањем легура из „црне масе” добијене третманом отпадних литијум-јон батерија. Редукцијом металних оксида и металних хлорида водоником долази до формирања металних прахова. Они су сакупљани у новом ултразвучном преципитатору.

Закључак: Процеси рециклирања могли би бити искоришћени за формирање водоника који може бити примењен у различитим редукционим процесима за производњу металних прахова. Нова истраживачка стратегија комбинује производњу водоника у процесу рециклирања „црне масе” из литијум-јон батерија заједно са ултразвучним распршивањем, термичким разлагањем капи и водоничном редукцијом.

Кључне речи: водоник, редукција, формирање, киселина, рециклирање.

Paper received on / Дата получения работы / Датум пријема чланка: 14.03.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 12.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 14.06.2023.

Macroeconomic aspects of comprehensive costs of assets as a prerequisite for equipping the defense system with weapons and military equipment

Aleksandar O. Savić[a], *Milan* M. Mihajlović[b], *Ivan* D. Božović[c]

[a] Ministry of Defence of the Republic of Serbia,
Military Technical Institute, Belgrade, Republic of Serbia,
e-mail: aleksandar22071993@gmail.com, **corresponding author,**
ORCID iD: https://orcid.org/0000-0002-9640-1583

[b] University of Defence in Belgrade, Military Academy,
Belgrade, Republic of Serbia,
e-mail: milan.mih83@gmail.com,
ORCID iD: https://orcid.org/0000-0001-7949-2631

[c] University of Priština - Kosovska Mitrovica, Faculty of Economics,
Kosovska Mitrovica, Republic of Serbia,
e-mail: ivan.bozovic@pr.ac.rs,
ORCID iD: https://orcid.org/0000-0001-6400-7461

DOI: 10.5937/vojtehg71-44145; https://doi.org/10.5937/vojtehg71-44145

FIELD: military science, public procurement
ARTICLE TYPE: review paper

Abstract:

Introduction/purpose: The activity of managing the budget funds of the Ministry of Defense and the Serbian Armed Forces (MoD and AF) does not accept even minimal mistakes in the procurement of weapons and military equipment (WME). Equipping the Serbian Armed Forces with weapons and military equipment must be economically justified because a large part of the budget is allocated for that purpose. The goal of the research is to look at the economic aspect of treating costs as a prerequisite for the process of equipping the defense system with weapons and military equipment.

Methods: For the purposes of the research, we used analytical and descriptive methods in order to see the comprehensive costs of assets that precede the effective equipping of the Ministry of Defense and the Armed Forces with WME. The research included the analysis of 18 review and research papers, which we analyzed in accordance with the Rulebook on equipping the Serbian Armed Forces with weapons and military equipment.

Results: The results of the research indicate that economic justification is expressed implicitly by the ratio of intangible benefits and achieved goals to the invested funds. The most common reason why economic *justification is not expressed explicitly by the difference between the initial investment and the final asset quantity is the existence of a number of circumstances for making wrong investment decisions. Also, if the costs are not considered in detail during the entire life cycle of the investment, it can be assumed that the planned target result is not certain.*

Conclusion: The research indicates that not considering costs during the entire life cycle of the investment is the main reason for unplanned investments in the later stages and the emergence of numerous problems in the functioning of the defense system.

Keywords: accounting inclusion, expenses, equipping, weapons and military equipment, life cycle.

Introduction

The defense system in the Republic of Serbia is constantly exposed to economic, financial, social and political restrictive conditions. The Ministry of Defense and the Serbian Armed Forces are considered the main elements of the defense system and are required to work on the development of the capabilities, the physical and psychological preparedness of their employees and the development and modernization of weapons and military equipment. However, budget funds intended for these purposes are established and repeated year after year.

In order for the defense system to function successfully under these conditions, it is necessary to establish resource management, i.e. a modern management approach aimed at realizing realistic and sustainable development strategies. The management approach is based on interdisciplinary analysis of problems, astute forecasting of conditions and long-term planning, which avoids deviation from pre-defined goals during a change of government and abandoning the previously adopted projects and solutions.

Significant investments in the Serbian Armed Forces, i.e. significant equipping of the military forces with weapons and military equipment, exceed the scope of work and capabilities of the Ministry of Defense and the Serbian Armed Forces. For these reasons, it is necessary for the state to get involved in this kind of investment process, which, by optimizing the use of financial resources at the state level, will provide additional financial resources for the functioning of the Defense System. The Ministry of Defense is a state institution that includes the Serbian Army. As such, it must manage allocated budget funds in a controlled manner. The question of the justification of investment in equipping the Serbian Armed Forces with weapons and military equipment is of fundamental importance both for the Ministry of Defense and for the society in general.

An investment involves a whole series of process activities that can be divided into the following areas: planning, preparation, realization and execution. Investment consists of the following basic elements: investor, investment project, interest and discount rate (Todorović, et al, 2000). The interest rate and the discount rate represent the amount of financial resources that are invested, the planned period for the realization of the investment project and the expected results.

Investing involves the process of exchanging something known for some expectations and benefits in the future. Uncertainty and time dispersion of values are considered the basic characteristics of investment. The degree of uncertainty of all factors in the future and their effects are directly related to the investment period.

That is why the management of investments is considered necessary when allocating large budget funds for an investment project, as well as when there is a high degree of risk for achieving the set goals. In almost all countries, investments are regulated by law as a process realized through several stages (Jovanović, 2006): pre-investment analysis, development of an investment program, making a decision on the realization of the investment, creation of technical documentation, realization of the investment project and putting the investment into operation.

In the Republic of Serbia, investment in weapons and military equipment for the needs of the Ministry of Defense and the Serbian Army is regulated by law. The reform of the public sector, which is carried out in the Republic of Serbia, covers all areas, including the defense system. As part of this reform, significant attention is directed to the optimization of total costs, even individual costs. This leads to the development of an adequate accounting methodology for determining the costs of the lifetime of assets, with teamwork and cooperation among technical and tactical procurement managers, designers and experts for integral logistic support (Stanković et al, 2020).

The goal of the research is to apply the approach of integral logistical support of weapons and military equipment in the area of accounting, based on the principles of a systemic approach. This paper also aims to make certain theoretical and empirical knowledge about costs available to the public, in order to create a suitable basis for their improvement.

Investing in weapons and military equipment for the needs of the defense system

Investing in weapons and military equipment for the needs of the Ministry of Defense and the Serbian Armed Forces is normatively regulated by the Rulebook on equipping the Serbian Army with arms and military equipment (Službeni vojni list, 12/2022). Regarding the period up to 2016, when the new Rulebook on equipping the Serbian Armed Forces with weapons and military equipment was adopted (Službeni vojni list, 26/2016), it can be stated that for almost two decades until then, the Rulebook on equipping the Yugoslavia Army with weapons and military equipment in peace (Službeni vojni list, 25/1996), was not harmonized with the requirements of the time and the real situation. Also, individual National Defense Standards 0477/83, 1096/85, 8196/92 and 9000/97 were considered normative documents that regulate the process of equipping the Serbian Armed Forces with weapons and military equipment.

The Rulebook specifies the technical and tactical bearers and bodies responsible for development and research, defining the maintenance system, procurement, etc. Through the process of planning, programming, research, development, production, testing and procurement, the Serbian Army is equipped with weapons and military equipment. In accordance with the Rulebook, a model with the following activities was defined for equipping the Serbian Armed Forces with weapons and military equipment:

- research and own development,
- development of copying according to the sample, i.e. according to the obtained license,
- development of cooperation with a business partner from abroad,
- procurement of imported funds,
- procurement of assets from the domestic market, and
- receiving donations from the country and abroad.

Also, the Rulebook determines the course of the process, with a detailed explanation and determination of the activity holders, subjects in the process and documents that should be prepared in the preparation of the proposal for making a decision on investment in equipping the Serbian Armed Forces with weapons and military equipment. A tactical study, a preliminary analysis and an implementation program are considered the basic documents at the beginning of the process of equipping with weapons and military equipment in accordance with the Rulebook. The tactical study is a document that is not mandatory in all processes of equipping with weapons and military equipment, and its preparation depends on the specific case. In contrast to the tactical study, the preliminary analysis and the implementation program are considered mandatory documents, and during their preparation, the focus is placed on the technical and technological aspect of the equipment analysis. When preparing the previous analysis and the implementation program, there is also an economic aspect, specifically the aspect of costs, but its more detailed analysis is not carried out.

When preparing the preliminary analysis, one part of the document should include the projection of costs and the conditions of development, production, cost of assets, equipment, investment, deadline for execution and integral technical security. However, the Rulebook does not define the need to consider the total costs during the lifetime of assets. In the implementation program document, the costs are stated in more detail within the framework of the technical and economic analysis, but still without specific instructions on their time calculation.

The analysis of the treatment of the material and the financial aspect of the investment in equipping the Serbian Armed Forces with weapons and military equipment was carried out through a case study. The analysis determined a different approach to the treatment of the mentioned investment activity. In certain situations, only the static aspect is present, while the dynamic aspect and the aspect of total costs are not considered. Whether an investment project will be accepted depends on the percentage of satisfaction of the conditions that the project requires, e.g. maximizing the relationship between effects and investment. According to Jovanović (2006), investment projects can be evaluated statically and dynamically. The static aspect is applied to pre-investment project activities and is mainly oriented towards small and medium-sized projects. In contrast to the static one, the dynamic aspect is mainly used in investment project activities. It is also oriented towards small and medium enterprises. However, the dynamic aspect is also oriented towards large companies, but with pre-investment project activities. Equipping the Serbian Army with weapons and military equipment is considered a large project, and it is necessary to conduct an adequate research study before making an investment decision. It is important to note that the existing regulations and practice of equipping the Serbian Armed Forces with weapons and military equipment do not fully treat the material and financial aspect, so investment decisions are made on the basis of intuition or empirical knowledge, which creates a risk in meeting the set goals.

Impossibility of adequately assessing the justification of investments occurs most often in the pre-investment period, due to the impossibility of monitoring the costs of investments in equipping the Serbian Armed Forces with weapons and military equipment. Also, during the period of exploitation of assets, unforeseen costs arise, with huge differences from the planned ones, which raises the question of the justification of the investment, the usability of weapons and military equipment and their expediency (Vukosavljević et al, 2021). The problem that arises in connection with unplanned costs is also related to organizational and functional entities that participate in the investment project and are considered technical and technological experts. On the other hand, they are not experts in the economic field, so it is necessary to include this type of field in education at all levels of schooling in the defense system (Andrejić, 2001).

Conditions for efficient legal procurement of weapons and military equipment

In the process of procuring weapons and military equipment, it is necessary to make a strategic, management, operational and administrative decision in a safe and expedient manner. In this way, the acquisition of assets is ensured at a certain time, when needed, and at the optimal price. The detailed activities needed to be taken into consideration before making a certain decision are:

The strategic decision is preceded by planning and developing the organization and procurement infrastructure, determining the most adequate way of using weapons and military equipment, positioning the standards to be applied, establishing a system of internal financial control, as well as material and financial reporting.

In order to make a smooth management decision, it is necessary to determine the quality and quantity of the procurement that can be carried out by the procurement group, to plan and coordinate the way of operation of the procurement itself, to carry out training and enable persons to implement the procurement procedure and finally to carry out the procedure of measuring the procurement results (Jestrović & Jovanović, 2022).

The operational decision requires the specification and examination of the method of supply of goods and services, evaluation of suppliers' offers, negotiations with them and monitoring of contract and project implementation.

Processing and dispatching purchase orders, checking documentation related to the delivery and receipt of goods (Avakumović et al, 2021), invoices, reports on services performed, payment orders and other documents, as well as keeping records of the entire procurement process are activities that fall within the scope of administrative decisions.

In order to establish an effective legal procurement system in the Ministry of Defense and the Serbian Army, a good knowledge of law and legal procedures is necessary. Appropriate positioning of the procurement service within the Ministry of Defense should also be carried out. Normative regulations of the procurement procedure, adequate selection, training and education of employees and compliance with standards of ethical behavior are also tasks for the successful functioning of the procurement system in the Ministry of Defense and the Serbian Armed Forces.

It is necessary to regulate the basic tasks and obligations of the heads of organizational units in the Ministry of Defense and the Serbian Armed Forces by secondary legal acts, to prescribe the tasks and obligations of officials who are directly involved in the procurement system, including all others who directly or indirectly influence the procurement process, such as deciding on the selection of bidders. In addition, it is necessary to define the activities, holders and responsibilities of all those involved in the procurement process.

Accounting coverage of the costs of weapons and military equipment

Costs are considered a significant indicator for equipping the Army with weapons and military equipment, bearing in mind that budget funds for defense purposes are limited (Mihajlović & Savić, 2022). The defense system must pay special attention to costs, because in conditions of inflation there is an increase in the cost of acquiring weapons and military equipment. Recently, with the change in the procurement system, there is also a comprehensive overview of the costs of exploitation and support in the costs of the life cycle. In the process of procuring weapons and military equipment, the costs incurred can be observable and unobservable (Đorđević & Krstić, 2020). Observable costs are those incurred when equipping units and institutions of the Ministry of Defense and the Army and purchasing assets. They are tied to the tactical carrier, i.e. to the authorities responsible for research, development, improvement and adoption of material resources within their jurisdiction.

In contrast to observable costs, unobservable costs are higher and arise when performing a greater number of activities in various industries. However, as their name suggests, such costs are not noticeable and tactical carriers usually do not consider them. Costs of distribution, maintenance, training, inventory, disposal, removal, etc. are considered unobservable costs, i.e. costs that are not considered.

In the process of procuring weapons and military equipment and calculating the costs incurred during the entire project, all the mentioned costs must be taken into account. Cost calculation can be presented in several ways, that is, several alternative cost solutions that meet the optimal criteria can be offered. In this way, the problem of a multi-criteria nature is solved, regardless of whether it is an optimal combination of costs or the best model (Petrović et al, 2012). The problem of solving a multi-criteria model is given in Table 1.

Table 1 – Problem of solving a multi-criteria model (Petrović et al, 2012)
Таблица 1 – Проблемы решений в многокритериальной модели (Petrović et al, 2012)
Табела 1 – Проблем решавања модела вишекритеријумске природе (Petrović et al, 2012)

		Criterion				
		K1	K2	.....	Kn	Model value
	Model 1					
	Model n					
The degree of difficulty of the criteria						
	Selection of models in accordance with the chosen criterion and its weight					

The problem of solving a multi-criteria model can be dealt with using a number of different methods and techniques. In their research, Drenovac A. & Drenovac B. (2012) singled out a special example of the choice of method and decision criteria. Also, Milićević & Župac (2012) presented the procedures for implementing the methods, with the aim of solving the problem of determining the weight of the criteria. A multi-criteria problem is usually solved by choosing a management model, directed towards the asset being adopted, provided that it meets the optimal requirements at the lowest cost.

During the service life of assets, the costs of acquisition, exploitation and support and disposal are identified.

Acquisition costs are identified through cost analysis and are incurred only once during the asset service life. Also, other costs are identified through cost analysis, but unlike acquisition costs, they arise constantly during the use of assets. Costs incurred during the renewal of resources for the exploitation and provision of services to a system or subsystem during its life cycle are called exploitation costs. They can be costs of acquiring and storing energy sources, ammunition, fuel and the like (Ivanova & Ristić, 2020). Disposal costs also refer to the costs of acquiring the same assets to replace destroyed and worn-out assets. With disposal costs in situations where they depend on some variable, it is necessary to find a way to consider them separately. Otherwise, they are not considered separately, but are an integral part of the exploitation and support costs.

The cost analysis assesses the degree of inflation, the decline in the purchasing power of the population, the decrease in the value of the currency, the growth of discount and interest rates at which loans are granted to commercial banks and households, and other factors that positively and negatively affect the amount of costs. Cost planning is done on the basis of historical data and facts, projections, proposals and cost forecasts. When planning costs, their quantitative and qualitative criteria should be taken into account.

All costs arising in the life cycle of assets can be separated into group costs and individual costs. In this respect, there are acquisition, exploitation and disposal cost groups.

Acquisition costs represent initial visible costs, that is, the costs of initial investments in the development and purchase of assets. They can be divided into costs incurred during research and development of assets and those incurred during investment. They are not decisive when making a decision on the choice of assets from the aspect of costs in the life cycle of assets. Therefore, the initial price does not play an important role for the choice of specific assets. However, this does not mean that when analyzing acquisition costs, one should not pay attention to the total purchase price of assets with equipment, costs of logistics, transport, additional testing, risk and other costs of acquisition and distribution of assets.

Exploitation costs represent the largest group of costs, accounting for 70% of total costs. Exploitation costs are divided into operational costs and logistical support costs.

Operational costs include the costs of training personnel to handle the equipment, the costs of further training and improvement of personnel, the costs of personnel wages, the preparation of accompanying documentation of the equipment, the use of ammunition, fuel and lubricants, as well as other costs incurred during the use of the equipment.

Logistics support costs are constantly incurred and include the following costs: costs of personnel training for asset maintenance, costs of continuous training and improvement, costs of spare parts procurement, their storage, as well as storage of ammunition, fuel and lubricants, costs of procurement of maintenance equipment, periodic testing and preparation of logistic documentation, costs of transportation of assets, construction of facilities and premises for the use and maintenance of assets, costs of collecting the database in the accounting information system and its functioning through nomenclature processing of funds (Klincov et al, 2022).

The costs of removing assets are called asset disposal costs. They can be particularly high for substances that are hazardous to the environment, and it is necessary to analyze them additionally. However, they can at the same time bring a certain amount of income by assigning or selling them, which depends on the way of conducting the policy of equipping and using assets. Efficiency and effectiveness are important principles in these costs. Disposal costs include the following costs: the cost of decommissioning assets, the cost of decommissioning assets and equipment for the use and maintenance of those assets, the cost of retraining personnel to work on other assets and the cost of analyzing costs in the life cycle of assets in order to create a database in the accounting information system.

The integral logistics support system analyzes certain subgroups of costs, which are defined by the standards for equipping the Serbian Armed Forces with weapons and military equipment. Depending on the costs, certain subgroups of costs need to be analyzed in the smallest detail, because they can be significant when choosing the type of weapons and military equipment for the Army. In the system of integral logistical support of weapons and military equipment, it is important to pay attention to the maintenance of assets, equipment for maintenance and equipping, support for supply, transport, handling and storage, care for people, i.e. employees, infrastructure, technical documentation and IT support (Stevanović et al, 2019).

In the maintenance of weapons and military equipment, the level and task of maintenance, reliability, continuity, maintenance time, cycle time by levels and tasks, operational availability, maintenance technology, as well as the number of annual interventions are monitored.

Procurement of maintenance equipment is carried out according to the quantity, type and location of the equipment, future intensity of its use, readiness for use and requirements for its maintenance. The following elements are classified under the support in the supply of the necessary weapons and military equipment: the level of repair achieved and the location of the assets, the required quantity and quality of spare parts, components and parts for repair, problematic processes, the frequency of replacing parts, the level of depreciation, aging and available stock, storage time period and conditions, time period and procurement cycle. During transport, handling and storage, each user should take care of the quantity, type, location, packaging and dispatching of assets, their storage in containers and other packaging, conservation and the costs of transport and storage. Care for people, i.e. employees, refers to the amount of trained staff and the required level of training, the intensity of training, indirect work on training per employee, the requirement for initial training, the necessity of having training aids and the organization of training. Infrastructure includes the necessity of a facility for training, storage for assets and capital equipment, tools and special devices for handling assets, installation network for servicing and maintenance, authorities for managing microclimatic conditions and facilities, as well as auxiliary authorities for maintenance and cleaning of facilities. The requirements of technical documentation and information support require the acquisition and production of technical manuals, manuals, instructions for operation and maintenance, procedures, etc., the formation of a database on weapons and military equipment, the production of reports on exploitation and maintenance, nomenclature processing of the assets and, finally, the construction or implementing an accounting information system (Savić et al, 2018).

Accounting coverage of the costs of specific weapons and military equipment

For the purposes of this research, the model of Prof. Kanga from the USA is adapted using the formula method in an Excel spreadsheet. As data on the costs of weapons and military equipment and other confidential information are unavailable to the public, the research was conducted on the basis of approximate data. This was intended to examine the mutual influence of the data, how they influence each other and what is their individual impact on the total cost of weapons and military equipment.

For the research sample, the model of prof. Kanga considered identical aircraft from two squadrons at different airports. In considering the initial purchase price, i.e. the cost of purchasing the aircraft, the prices of the aircraft and equipment for servicing and maintenance, the costs of acquisition and distribution, as well as the costs of basic personnel training were taken into account. The costs of maintenance and modernization of the aircraft in the first five years are almost non-existent, because they are new assets under warranty. After five years, and even later, certain regular investments in the aforementioned assets are required, which leads to an increase in maintenance costs. On the other hand, at the end of half a century of use of the assets, higher costs appear in connection with improvement and modernization, as well as additional tests of the assets for their safe use. Considering the lifetime of the assets, we also have a constant increase in operating costs. However, at the end of the asset useful life, it is possible to sell the asset at a favorable price and in that case generate income instead of a negative cost.

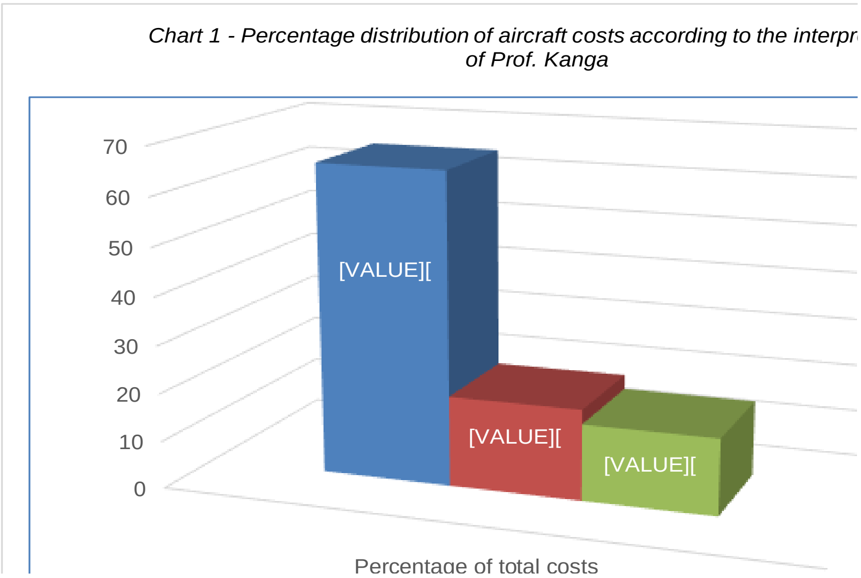


Figure 1 – Percentage distribution of aircraft costs according to the interpretation of Prof. Kanga (Andrejić & Soković, 2009)
Рис. 1 – Процентное распределение затрат на воздушные суда в соответствии с интерпретацией профессора Канга (Andrejić & Soković, 2009)
Слика 1 – Процентуална расподела трошкова за авионе, према тумачењу проф. Канга (Andrejić & Soković, 2009)

If we look at the total costs of the aircraft (Chart 1, Figure 1), It can be concluded that the largest part of the total costs are actually operational costs of using and maintaining the asset (65%), followed by modernization and testing costs (18%) and training costs and other personnel costs (17%).

Through a detailed analysis of the squadron, it was determined that the costs of using and maintaining the assets are the highest because there is a lack of manpower for the said assets, both pilots and other personnel who would be engaged in its preparation and maintenance. In that case, there would be no basic costs for the said personnel (salaries, fees, daily allowances, etc.), but the costs arising as a result of inadequate management and maintenance of the said assets (which are more significant in relation to the personnel costs) would be higher. The costs related to the personnel who handle, work on the preparation and maintenance of the assets are invisible costs which are constantly present and which are decreasing due to the radical reduction of workers. Also, the non-targeted hiring of workers directly affects the increase in operating costs, which means the engagement of trained soldiers under a contract for asset maintenance activities (Savić et al, 2021).

Modernization and testing costs are inversely related to maintenance costs. If maintenance costs decrease, the circumstances for inadequate maintenance increase, together with the costs of testing and modernization. For investing in the modernization of weapons and military equipment, in addition to money, time represents another important resource in these activities.

With training costs and other personnel costs, money and time are also essential resources for their management. Which resource is more important in this case depends on the conditions of acquisition, use, storage, maintenance and disposal of weapons and military equipment.

Conclusion

In the early stages of the development of weapons and military equipment, costs are determined and accounted for during the entire life of assets. In this way, it is possible to influence the total number of assets, as well as to reduce the costs of the asset service life through the change of projects. Accounting inclusion of costs in the Ministry of Defense and the Serbian Army requires and ensures efficient, effective and economical logistical support in the process of procurement of weapons and military equipment. In order to successfully manage costs, it is necessary to establish a system of internal financial control in the earlier stages of designing the procurement process. The establishment of logistical support and the implementation of internal financial control require ensuring operational readiness and linking it to the costs of the lifetime of assets.

The concretization of the elements of internal logistic support is carried out in the phase of realization of the prototype development of weapons and military equipment, which realizes the constant dependence of the technical solution and project in order to achieve the maximum availability or efficiency of assets with minimum total costs. This aims to obtain a tool that will perform tasks with optimal efficiency and costs both in peace and war with very little uncertainty. That is why this process of developing weapons and military equipment is considered the most economical.

Asset procurement costs are minimal in relation to the overall costs registered at the end of the asset service life because most of overall costs relate to asset use and maintenance. Maintenance and exploitation costs depend on the price of the working hour of the asset, while other costs are less affected by the lifetime of the asset. It is most expedient that the largest part of investment takes place in the initial stages through adequate handling and maintenance, in order to obtain an asset with the lowest possible costs during its life of use. All this needs to be regulated by a certain standard through application software solutions which enable multiple comparative analysis and the adoption of optimal solutions.

The process of equipping the Ministry of Defense and the Serbian Army with weapons and military equipment is multidisciplinary and multi-criteria and requires the formation of project teams for its management. The accounting inclusion of the costs of asset procurement enables an overview of the assets during their operational life in order to make the optimal decision. When accounting for costs, not all data are available, but some are obtained directly from manufacturers (who all want to sell their products at the best price). Some cost data are found in the asset databases and are based on historical facts. In this regard, it is not necessary to create a database that will collect information about future flows. Information can also be found with other partners who use identical or similar assets or use them in some other way (e.g. information on the reliability or time of failure of certain parts, etc.). All these data are used in the calculation of costs and their accounting inclusion, using adequate applicable mathematical methods that enable their precise determination.

When equipping the Ministry of Defense and the Serbian Army with weapons and military equipment, it should be borne in mind that these assets are procured for a period of 30 years or longer and that during that period they must be operationally capable of performing various tasks in various conditions. This includes forecasting the costs of their modernization or adaptation, with the aim of bringing them to a state of operational capability and efficiency. When predicting costs, the greatest attention is directed to logistics costs because they make up the largest part of total costs. In order to see total costs in the right way, it is necessary to develop and standardize the methodology of their calculation with the help of an adequate accounting information system. The role of accounting information systems is essential in all organizational systems, from the smallest to the largest ones. In order to properly account for the costs of assets and indicate their importance, it is necessary to study certain principles of logistical support at all levels of training and development of personnel in the defense system, as well as the costs that arise in them along with the way they are recorded and checked by the internal financial control system.

References

Andrejić, M. 2001. Methods and software for the support of planning in logistic organizational systems. *Vojnotehnički glasnik/Military Technical Courier*, 49(1), pp.36-52 (in Serbian). Available at: https://doi.org/10.5937/vojtehg0101036A.

Andrejić, M. & Sokolović, V. 2009. Integral logistic support means of armament and military equipment. *Vojnotehnički glasnik/Military Technical Courier*, 57(1), pp.32-53 (in Serbian). Available at: https://doi.org/10.5937/vojtehg0901032A.

Avakumović, J., Obradović, L. & Božić, G. 2021. Management and organization of teamwork in the function of sustainable development. *Održivi razvoj*, 3(2), pp.69-80 (in Serbian). Available at: https://doi.org/10.5937/OdrRaz2102069A.

Drenovac, A.Ž. & Drenovac, B.Ž. 2012. Possibilities of the application of multicriteria analysis and PROMETHEE methods, on an example of aircraft choice. *Vojnotehnički glasnik/Military Technical Courier*, 60(3), pp.125-142 (in Serbian). Available at: https://doi.org/10.5937/vojtehg1203125D.

Đorđević, D. & Krstić, D. 2020. The relationship between fiscal policy and sustainable development. *Održivi razvoj*, 2(1), pp.7-15 (in Serbian). Available at: https://doi.org/10.5937/OdrRaz2001007D.

Ivanova, B. & Ristić, S. 2020. Capital accumulation and concentration. *Akcionarstvo,* 26(1), pp.26-34 [online]. Available at: http://www.ipn.org.rs/uploads/35271/documents/akcionarstvo_slozeno_2020_(1).pdf (in Serbian) [Accessed: 20 April 2023].

Jestrović, V. & Jovanović, V. 2022. The role of corporate governance in sustainable development. *Održivi razvoj,* 4(1), pp.43-53 (in Serbian). Available at: https://doi.org/10.5937/OdrRaz2201043J.

Jovanović, P. 2006. *Upravljanje investicijama, 6. izdanje*. Belgrade: University of Belgrade - Faculty of Organizational Scinces (in Serbian). ISBN: 86-7680-094-4.

Klincov, R., Marjanović, N., Trnavac, D., Novović, M. & Obućinski, D. 2022. Understandings of economic laws in modern economic theory. *Akcionarstvo,* 28(1), pp.99-114 [online]. Available at: http://www.ipn.org.rs/uploads/35271/documents/akcionarstvo_slozeno_2022.pdf (in Serbian) [Accessed: 20 April 2023].

Mihajlović, M. & Savić, A. 2022. The role of the budget in financing the defense system of the Republic of Serbia. *Ekonomist,* 1(1), pp.16-27 [online]. Available at: https://ekonomist.org.rs/wp-content/uploads/2022/05/Ekonomist-br.-1.pdf (in Serbian) [Accessed: 20 April 2023]. ISSNe: 2812-9725.

Milićević, M.R. & Župac, G.Ž. 2012. An objective approach to determining criteria weights. *Vojnotehnički glasnik/Military Technical Courier*, 60(1), pp.39-56 (in Serbian). Available at: https://doi.org/10.5937/vojtehg1201039M.

Petrović, N.Č., Đedović, B.N. & Petrović, D.N. 2012. Project estimation and selection using the cost: Effectiveness analysis and multi-criteria analysis. *Vojnotehnički glasnik/Military Technical Courier*, 60(3), pp.168-187 (in Serbian). Available at: https://doi.org/10.5937/vojtehg1203168P.

Savić, A.O., Avakumović, J.Č. & Tasić, S.S. 2021. The influence of intellectual capital on supply chain management of the Military Technical Institute. *Tehnika*, 76(4), pp.490-498 (in Serbian). Available at: https://doi.org/10.5937/tehnika2104490S.

Savić, A., Miljković, M. & Damnjanović, T. 2018. Role of accounting documents accounting information system. *Oditor*, 4(3), pp.110-127 (in Serbian). Available at: https://doi.org/10.5937/Oditor1803111S.

-Službeni vojni list. 25/1996. *Pravilnik o opremanju Vojske naoružanjem i vojnom opremom u miru*. Belgrade: Ministarstvo odbrane Republike Srbije (in Serbian).

-Službeni vojni list. 26/2016. *Pravilnik o opremanju Vojske Srbije naoružanjem i vojnom opremom*. Belgrade: Ministarstvo odbrane Republike Srbije (in Serbian).

-Službeni vojni list. 12/2022. *Pravilnik o opremanju Vojske Srbije naoružanjem i vojnom opremom*. Belgrade: Ministarstvo odbrane Republike Srbije (in Serbian).

Stanković, V., Mrdak, G. & Miljković, M. 2020. Economic-legal analysis of international investments. *Oditor,* 6(3), pp.89-122 (in Serbian). Available at: https://doi.org/10.5937/Oditor2003089S.

Stevanović, T., Antić, Lj. & Savić, A. 2019. Specifity of performance measurement in the ministry of defense and the Serbian armed forces. *Facta universitatis, Series: Economics and Organization*, 16(3), pp.283-297. Available at: https://doi.org/10.22190/FUEO1903283S.

Todorović, J., Đuričin, D. & Janošević, S. 2000. *Strategijski menadžment, III izmenjeno izdanje*. Belgrade: Institut za tržišna istraživanja (in Serbian). ISBN: 86-81803-09-3.

Vukosavljević, D., Kaputo, J., Tešić, A. & Vukosavljević, D. 2021. *Macroeconomic environment and the public sector: Place and role*, *Oditor,* 7(3), pp.37-50 (in Serbian). Available at: https://doi.org/10.5937/Oditor2103037V.

Макроэкономические аспекты комплексной стоимости денежных средств как обязательное условие оснащения системы обороны вооружением и военной техникой

Александар О. Савич[а], *Милан* М. Михайлович[б], *Иван* Д. Божович[в]

[а] Министерство обороны Республики Сербия, Военно-технический институт, г. Белград, Республика Сербия, **корреспондент**

[б] Университет обороны в г. Белград, Военная академия, г. Белград, Республика Сербия

[в] Приштинский университет – г. Косовска Митровица, экономический факультет, г. Косовска Митровица, Республика Сербия

РУБРИКА ГРНТИ: 78.75.43 Финансирование военных расходов
78.75.45 Военно-экономические связи
78.75.49 Планирование военной экономики
78.75.73 Статистика, учет и отчетность. Технико-экономический анализ в военном деле
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: В управленческой деятельности бюджетными средствами Министерства обороны и Вооруженных сил Сербии (МО и ВС) недопустимы даже мельчайшие ошибки при закупках вооружения и военной техники (ВВТ). Оснащение сербских Вооруженных сил вооружением и военной техникой должно быть экономически оправдано, поскольку на эти цели выделяется значительная часть бюджета. Цель исследования состоит в рассмотрении экономического аспекта затрат как необходимого условия в процессе оснащения системы обороны вооруженением и военной техникой.

Методы: Для достижения цели анализа суммарных затрат по эффективному оснащению Министерства обороны и Вооруженных сил вооружением и военной техникой использовались аналитические и описательные методы. В ходе данного исследования проведен анализ 18 обзорных и исследовательских работ. Анализ проведен в соответствии с Регламентом оснащения Вооруженных сил Республики Сербия вооружением и военной техникой.

Результаты: Результаты исследования свидетельствуют о том, что экономическая обоснованность капиталовложений имплицитно выражается соотношением нематериальных выгод и достигнутых целей. Наиболее распространенной причиной, по которой экономическая обоснованность неэксплицитно выражается в разнице между первоначальными инвестициями и итоговой суммой капиталовложений, является наличие ряда обстоятельств, влияющих на принятие ошибочных инвестиционных решений. Кроме того, можно предположить, что прогнозируемый целевой результат не будет соответствовать намеченным планам, если детально не анализировать затраты в течение всего жизненного цикла инвестиционного проекта.

Выводы: Результаты исследования показали, что неучет затрат в течение всего жизненного цикла инвестиционного проекта является основной причиной незапланированных инвестиций на более поздних этапах и возникновения многочисленных проблем в функционировании системы обороны.

Ключевые слова: охват бухгалтерского учета, затраты, оснащение, вооружение и военная техника, жизненный цикл.

Макроекономски аспекти свеобухватних трошкова средстава као предуслов за опремање система одбране наоружањем и војном опремом

Александар О. Савић[а], *Милан* М. Михајловић[б], *Иван* Д. Божовић[в]

[а] Министарство одбране Републике Србије, Војнотехнички институт, Београд, Република Србија, **аутор за преписку**

[б] Универзитет одбране у Београду, Војна академија, Београд, Република Србија

[в] Универзитет у Приштини – Косовска Митровица, Економски факултет, Косовска Митровица, Република Србија

ОБЛАСТ: војне науке, јавне набавке
КАТЕГОРИЈА (ТИП) ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Активност управљања буџетским средствима Министарства одбране и Војске Србије (МО и ВС) не прихвата ни минималне грешке у набавци наоружања и војне опреме (НВО). Опремање Војске Србије наоружањем и војном опремом мора бити економски оправдано, јер се велики део буџетских средстава издваја за ту намену. Циљ истраживања јесте да се сагледа економски аспект третирања трошкова као предуслов процеса опремања система одбране наоружањем и војном опремом.

Методе: За потребе истраживања коришћене су аналитичке и дескриптине методе ради сагледавања свеобухватних трошкова средстава неопходних за ефикасно опремање МО и ВС средствима НВО. Анализирано је 18 прегледних и истраживачких радова, у складу са Правилником о опремању Војске Србије наоружањем и војном опремом.

Резултати: Указано је да се економска оправданост исказује имплицитно односом нематеријалних користи и остварених циљева према уложеним новчаним средствима. Најчешћи разлог због којег се економска оправданост не исказује експлицитно разликом почетног улагања и крајњег износа средства јесте постојање већег броја околности које утичу на доношење погрешних инвестиционих одлука. Такође, ако се током целог животног циклуса инвестиције трошкови не разматрају детаљно, може се претпоставити да и планирани циљни резултат није сигуран.

Закључак: Истраживање указује да неразматрање трошкова током целог животног циклуса инвестиције представља основни разлог непланираних улагања у каснијим фазама, што доводи и до настанка бројних проблема у функционисању система одбране.

Кључне речи: рачуноводствено обухватање, трошкови, опремање, наоружање и војна опрема, животни циклус.

Paper received on / Дата получения работы / Датум пријема чланка: 24.02.2023.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 15.06.2023.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 17.06.2023.

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2023, Vol. 71, Issue 3

Кинеске и америчке вишекратне свемирске летелице[1]

Сателитске слике ваздухопловне базе Lop Nor у Кини која се доводи у везу са развојем тајне свемирске летелице

Суборбитални транспортер за вишекратну употребу – „X-37 са кинеским карактеристикама у савременим условима” – 16. јула 2021. године стабилно је слетео на аеродром у Алкси, у северној кинеској аутономној области Унутрашња Монголија током демонстрације лета и верификације пројекта. Раније тог дана, транспортер је лансиран из центра за лансирање сателита Јиукуан у северозападној кинеској пустињи Гоби, око 800 километара од аеродрома Алксе. Његова прва летна мисија била је врло успешна. Развијен у корпорацији China Aerospace Science and Technology Corporation (CASC), суборбитални транспортер за вишекратну употребу може се користити у систему свемирског транспорта.

Кинеска експериментална свемирска летелица за вишекратну употребу вратила се на планирано место слетања 6. септембра 2020. године, након дводневне операције у орбити. Летелица је лансирана ракетом-носачем *Long March-2F* из центра за лансирање сателита Јиукуан у северозападној Кини, 4. септембра 2020. године. Кружила је у орбити димензија 331×347 километара, под нагибом од 50,2 степена. Новинска

[1] www.globalsecurity.org/ 21-10-2021

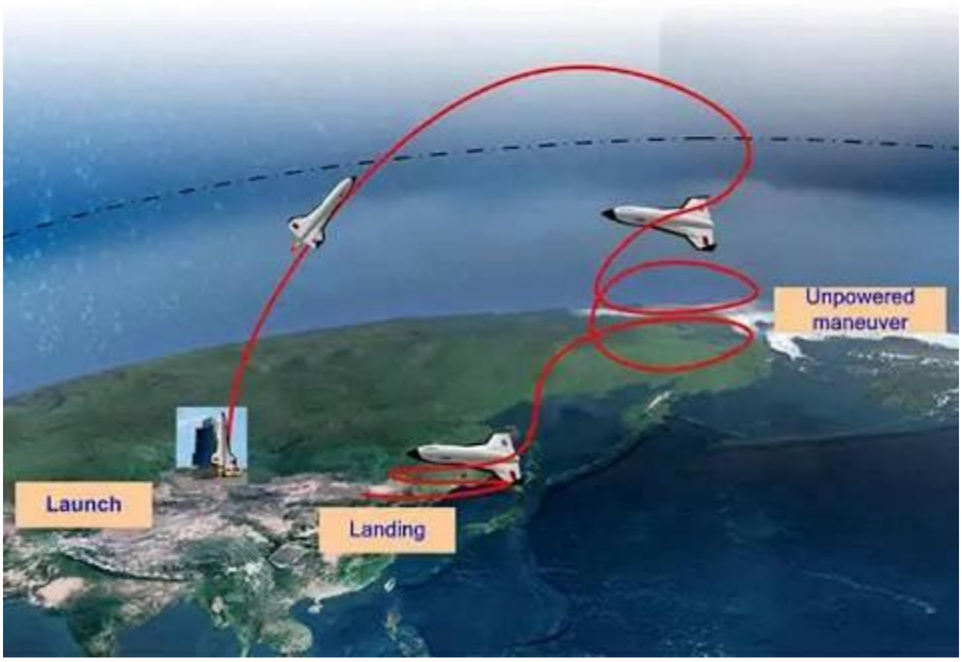
агенција Синхуа је саопштила да је „успешан лет означио важан напредак земље у истраживању свемирских летелица за вишекратну употребу и да се очекује да ће понудити адекватан и јефтин повратни транспорт за мирно коришћење свемира".

Летелица је данима кружила у орбити, емитујући свој положај, а касније је изашла из орбите и слетела хоризонтално као обичан авион. Током свог лета тестирала је технологије за вишекратну употребу. Лансирање је представљало 14. мисију ракете-носача *Long March-2F*, бустера носивости 8.400 кг. Трансатмосферско возило *Shenlong* је мала свемирска летелица без посаде развијена у Кини у оквиру програма 863. Кинески корисници интернета називају авионе *J-20, Dongfeng, Dongfeng 21D* и *Shenlong* „Три мускетара" Народне ослободилачке армије. Године 2007. на интернету су се појавиле фотографије летелице *Shenlong* на којима се видело да је она висила испод трупа бомбардера H-6, али до данас није било званичне потврде о аутентичности слика.

Shenlong виси испод трупа бомбардера H-6

Кина тренутно развија ваздушно-свемирски транспортер кодног назива *Shenlong* за који се каже да је сличан америчком орбитеру *X-37B* који је развила компанија „Боинг" у Сједињеним Државама До сада су званични детаљи о летелици *Shenlong* држани у тајности, а избрисане су и веб-странице које су раније објављивале релевантне информације.

Shenlong је прототип кинеске роботске свемирске летелице која је врло слична америчкој свемирској летелици X-37.



Метод операција свемирске летелице

Вишекратне свемирске летелице могле би обезбедити значајне предности у свемирским операцијама, омогућујући брзо пребацивање особља и терета на већим даљинама, али и убацивање одређених товара у орбиту. Оне могу водити и офанзивне акције против непријатељских снага. Већ дуже време појављују се разна нагађања о томе шта америчка војска ради са својим минијатурним спејс-шатлом *X-37B* који је под командом америчких свемирских снага.

Поменути спејс-шатл је само један од сличних пројеката које америчка војска води још од шездесетих година.

Амерички X-37B и експеримент са микроталасним зрацима[2]

Тајанствени X-37B лансиран је већ шест пута. Док је састав товара углавном познат, постоји један део који би могао да има огромне потенцијалне импликације у вези будућности управљања бежичним преносом енергије, као и дуготрајним погоном беспосадних летелица.

Мисија летелице X-37B има ознаку *Orbital Test Vehicle-6 (OTV-6) и U.S. Space Force-7 (USSF-7)*. Њен задатак је да утврђује ефекте космичке

[2] www.thedrive.com May, 2020

радијације и других „свемирских ефеката” на саднице биљака и друге материјале. Интересантно је тестирање експерименталног система који би могао да „ухвати” Сунчеву светлост и да је зрачењем проследи натраг на Земљу у облику микроталасних зрака. Питање је колико је реална употреба оваквог система само у мирнодопске сврхе?

Иначе, мисије америчког мини-шатла углавном су потпуно обавијене велом тајности.

Русија је испала из ове трке након пропасти спејс-шатла „Буран” који је развио бивши СССР.

X-37B

Да ли се Кина креће ка *FOBS* мисијама?[3]

FOBS је скраћеница за израз *Fractional Orbital Bombardment System,* што би у преводу значило фракционални орбитални систем бомбардовања.

Извештаји медија указују на то да је Кина тестирала систем за који се сматра да укључује планирајуће возило у оквиру фракционалног орбиталног система бомбардовања (*FOBS*).Тај систем за гађање нуклеарним оружјем поставља бојеве главе у ниску Земљину орбиту пре него што ће иницирати напуштање орбите нуклеарним бојевим главама у нападу на одабране циљеве. Неки детаљи тестирања и даље су нејасни, а

[3] www.iiss.org/

Кина је оповргла да постоје било какве активности у том правцу. Кина би била прва држава која би развила овакву врсту способности после Русије. Иако је питање да ли би систем *FOBS* стварно допринео Кини остварење стратешке предности, тест је демонстрирао наставак стратешког такмичења између Кине и САД у развоју ракетне технологије.

Амерички лист *Financial Times* известио је да је Кина „тестирала хиперсоничну ракету са потенцијалним нуклеарним пуњењем која је кружила око планете пре него што се спустила ка свом циљу", доказујући напредну свемирску технологију која је изненадила америчке обавештајне службе. У накнадном извештају се примећује да је овај тест извршен у јулу 2022. године, а да је касније извршен још један у августу са непознатим системом који је летео хиперсоничном брзином. Извори су навели да је бојева глава промашила свој циљ на непознатој локацији за „око 50 км". Такође је нејасно на ком делу трајекторије се одвојио планирајући пројектил од ракете носача. Међутим, иако се у извештају наводи да је планирајући пројектил „летео кроз ниску орбиту у свемиру пре крстарећег лета према свом циљу", претпоставља се да се радило о тестирању хиперсоничног планирајућег возила – *hypersonic glide vehicle (HGV)* тако што је матична летелица остала у горњој Земљиној орбити након усмеравања лета пројектила ка циљу. Кинески министар спољних послова је негирао извршење оваквог теста, појашњавајући да се радило о рутинском тестирању вишекратног свемирског возила.

FOBS није нова технологија. Совјетски Савез је развио *FOBS* под ознаком *R-36O (RS-SS-9 Mod 3 Scarp*) 1968. године, али га је повукао из оперативне употребе након потписивања споразума о ограничењу стратешког оружја (*SALT II)* који је изричито забранио употребу оваквих система. Сједињене Државе и Кина су, такође, показале интерес за смештање оваквог оружаног система у ниску Земљину орбиту. Једном када се оружје приближи својој мети, упалиле би се ретро ракете и избациле бојеву главу из орбите у атмосферу ка својој мети. Планирајуће возило би овај концепт подигло на виши ниво тако што би се омогућило маневрисање бојеве главе хоризонтално и вертикално ка мети када уђе у Земљину атмосферу.

Моптивација

Совјетски Савез је развио *FOBS* ради превазилажења ограничења својих стратешких ракетних снага у поређењу са америчким стратешким снагама које су имале базе на четири континента одакле су могле лансирати нуклеарне ударе. Такође, *FOBS* је омогућио Москви да избегава откривање совјетских ракета радарима за рано упозоравање у случају лансирања. Како су Совјети били мотивисани за развој *FOBS-а* ради превазилажења тадашњих и будућих америчких некинетичких ракетних пресретача, тако би и Кина могла бити мотивисана додатним могућностима избегавања садашње и будуће америчке противракетне одбране, укључујући и кинетичке пресретаче. Поставља се питање зашто би Кина наставила да развија носач *FOBS* уместо интерконтиненталних балистичких ракета великог домета које би избегле путању изнад Јужног пола, сличних руској интерконтиненталној ракети *Sarmat (RS-SS-X-29),* или да развија хиперсонично возило као што је руски *Avangard*,

Импликације

Неки амерички политичари су окарактерисали кинеске пробе *FOBS-а* као знак за узбуну и позив на амерички одговор. Међутим, поставља се питање да ли ће Кинези успети да развију овај систем онако како је пројектован, јер промашај циља од преко 50 км није сјајан резултат, мада треба рећи да се вероватно ради само о почетку испитивања система.

FOBS захтева кабасте ретро-ракете за деорбитирање бојеве главе. То значи да сам капацитет бојеве главе мора бити умањен, што није случај са класичним интерконтиненталним ракетама. На пример, бојева глава класичне интерконтиненталне ракете *R-36 (RS-SS-9 Mod 1 Scarp*) носи од 12 до 18 мегатона, док се процењује да систем R-*36O FOBS* има носивост од 1 до 3 мегатона. Како је у кинеском случају циљ промашен за више од 50 км, снага бојеве главе не може компензовати овакав недостатак.

Иако прилаз из неочекиваних праваца омогућује руковаоцима *FOBS*-а остваривање предности, нарочито зато што САД имају ограничену могућност покривања јужне хемисфере радарима за рано упозорење, садашњи и будући развој америчке ракетне одбране и развој нових и способнијих ракета пресретача на фиксним и мобилним платформама може умањити потенцијално преживљавање употребљених планирајућих *FOBS*.

Кина има око 100 интерконтиненталних ракета које могу циљати САД, као и потенцијалну могућност другог удара са својих шест нуклеарних балистичких подморница класе *Type-094 Jin.* Упркос својим тврдњама да неће прва нападати него да ће одржавати минималну способност одвраћања, постоје све јачи докази да се Кина креће ка модернизацији и експанзији свог нуклеарног арсенала према комплетирању тријаде и са опцијама првог и другог удара.

Развој *FOBS-а* са планирајућом бојевом главом следио би након кинеског категоричког одбијања разговора о контроли наоружања са Вашингтоном и убрзаног развоја и увођења у наоружање нових система за гађање нуклеарним бојевим главама што је и логично с обзиром на вишеструко веће америчке војне буџете и њихов разлаз са Русијом у погледу контроле нуклеарног наоружања.

Турски носач дронова[4]

Турска ратна морнарица је прославила улазак у службу свог новог адмиралског брода *TCG Anadolu*, тренутно свог највећег ратног брода, свечаном инаугурацијом одржаном отприлике три месеца након стварне испоруке брода због проблема са распоредом. *TCG Anadolu* је класификован као десантни брод, али званичници у Турској кажу да имају планове да га користе и као носач различитих нивоа наоружаних беспилотних летелица.

Заснован на дизајну шпанског десантног брода *Juan Carlos I, Anadolu* је положен у бродоградилишту Седеф у Истанбулу 2018. године. Брод је поринут само годину дана касније, а прелиминарни тестови су завршени 2022. године. Говорећи на церемонији испоруке, такође одржаној у Седефу, турски председник Реџеп Тајип Ердоган је приметио да је 70% брода изграђено од делова и компоненти произведених у Турској, укључујући и његово наоружање, борбене системе, радаре, способност инфрацрвене претраге и праћења, као и електронски систем ратовања.

Ердоган је, такође, изјавио да ће овај брод омогућити да Турска спроводи војне и хуманитарне операције у сваком делу света када год је то потребно.

Anadolu има типичну конфигурацију брода за десант хеликоптера (*LHD*) са великом полетно-слетном палубом. Намењен је да искрца снаге на копно током десанта користећи хеликоптере, пловила за искрцавање и лагана и тешка оклопна возила.

Ердоган је говорио о распону додатних способности које *Anadolu* такође може пружити, укључујући команду и контролу, медицинску подршку и хуманитарну помоћ.Истакао је и способност носача да носи и користи разне наоружане беспилотне летелице, што је концепт који Турска већ неко време предвиђа за брод. Пошто је првобитно наручен 2015. године, *Anadolu* је еволуирао у јединствено вишенаменско пловило које се може фокусирати и на операције беспилотних летелица. На овај начин би требало да превазиђе традиционалну употребу хеликоптера са људском посадом, делујући као лаки носач авиона за борбене беспилотне летелице.

Комбинација свих ових могућности омогућиће броду велику флексибилност за његову класу.

У фебруару ове године објављено је да ће брод бити подвргнут мањим изменама своје инфраструктуре како би се ефикасније подржале операције беспилотних летелица. То би требало да укључи увођење станица за контролу беспилотних летелица са сателитским терминалима за везе већег домета, као и инсталацију „система ваљака” на прамцу брода како би се помогло лансирање ових летелица, затим додавање система за заустављање на палуби како би се олакшало слетања беспилотних

[4] *www.thedrive.com april* 11, 2023

борбених летелица (*unmanned combat air vehicle – UCAV*) и сигурносних мрежа за прихватање њихових мањих типова.

Носач хеликоптера и дронова Anadolu

Према подацима које је објавило Министарство одбране Турске, *Anadolu* је дугачак 231 м, широк око 32 м и има депласман од 27.436 тона. Пловило може да развија максималну брзину од око 21 чвора са пуним оптерећењем, има радијус дејства од 14 500 км и може да врши мисије у трајању до 90 дана. У саопштењу за штампу, које је објавило министарство, такође се наводи да је *Anadolu* у стању да превезе један батаљон од 1.400 војника поред своје посаде коју чини око 400 морнара.

Што се тиче капацитета утовара копнених средстава, у саопштењу се додаје да је могуће утоварити 13 тенкова, 27 амфибијских јуришних возила, шест оклопних транспортера, 33 разна лака и тешка оклопна возила и 15 приколица. Такође, *Anadolu* може да носи до шест десантних пловила различитих типова на својој доњој плавној палуби, што би било кључно за преношење поменутих копнених возила и трупа на обалу.

Највише интересовања привукла је дискусија у вези са ваздушном ескадрилом. Брод има полетно-слетну палубу, површине 17.861 м, у такозваној скијашкој конфигурацији са шест места за слетање транспортних и јуришних хеликоптера, као и два места за слетање тешких транспортних хеликоптера.

Оклопна амфибијска јуришна возила у хангару носача TCG Anadolu

Задњи део новог турског брода

Наводи се да су то хеликоптери *T129 ATAK и AH-1W Super Cobra*, јуришни хеликоптери, противподморнички хеликоптери *SH-60B* и транспортни хеликоптери *AS532* Cougars, S-70/UH-60 Black Hawks и CH-47F Chinook. . Ердоган је такође изјавио да ће лаки тренажни авион-ловац TAI Hürjetв бити у могућности да користи палубу носача за полетање и слетање. Још увек није јасно да ли је ова могућност испитана у реалним условима или само у симулатору, али је интересантна.

AH-1W и SH-60B хеликоптери на носачу хеликоптера Anadolu

Anadolu може укрцати 12 посадних или беспосадних борбених авиона, 21 хеликоптер разних типова и наоружаних беспилотних летелица у зависности од врсте операција.

Тренутно се очекује да ће нови тип БПЛ са склопивим крилима *Bayraktar TB3* бити основна БПЛ на носачу хеликоптера. *То* је поморска верзија *БПЛ TB2* који је успешно прошао ватрено крштење на неколико различитих фронтова, а нарочито у Украјини. *Bayraktar TB3* је ипак наменски пројектован за могућност полетања и слетања на носаче авиона и амфибијске јуришне бродова са кратким полетно-слетним стазама.

Очекује се да ће нова верзија барјактара бити званично приказана на сајму наоружања TEKNOFEST 2023, који ће се одржати између 27. априла и 1. маја 2023. године на истамбулском аеродрому Ататурк, док се почетак летних испитивања очекује током ове године.

Компанија „Baykar" очекује да ће и њена беспилотна летелица *Kizilelma* на млазни погон бити део ваздухопловне групе носача *Anadolu* с обзиром на то да је и она пројектована за полетање и слетање са кратких полетно-слетних стаза. Ова летелица је и даље у развоју, а пробни лет је извршен у децембру 2022.године.

Турски званичници стоје иза БПЛ Bayraktar TB3 на палуби носача TCG Anadolu

Компанија је навела да ће лет БПЛ *Kizilelma* трајати до шест сати, док ће борбени радијус дејства бити око 800 км, а највећа висина лета до 10.700 м. Максимална брзина летелице биће близу једног маха, максимална маса при полетању 6.000 кг, укључујући подвесни терет од 1.500 кг.

Неизвесно је како ће овај брод са ограниченим простором управљати са оволико различитих борбених система, укључујући брзе млазне беспилотне летелице којима је потребан зауставни систем за слетање и вероватно цела дужина полетне стазе за узлетање са пуним борбеним товаром.

Претварање носача *Anadolu* у матични брод за беспилотне летелице није био првобитни циљ пројекта с обзиром на то да је брод предвиђен за смештај летелица *F-35B* или *AV-8B*. Током 2019. године, САД су избациле Турску из програма *F-35* због тога што је набавила руске противавионске системе *S-400* иако је Турска већ инвестирала 1,4 милијарде долара у развој програма *F-35* у којем су учествовале бројне турске компаније производећи стотине делова за невидљиви ловац.

Турска је учествовала у преговорима у вези с набавком вишка ловаца *Harrier* са вертикалним полетањем и слетањем америчког маринског корпуса, али се, бар засад, ти преговори нису финализовали. Пошто је Турска остала без ловца због кога је и градила овакав носач, одбрамбена индустрија је била принуђена да се усмери на своје испитане беспилотне летелице.

Компјутерски обрађена слика полетања наоружаних БПЛ са носача

Овим носачем хеликоптера и БПЛ Турска планира да регионално, па чак и глобално, пројектује своју снагу. С друге стране, недавни земљотреси и поплаве могли би да оправдају и другачију употребу оваквог брода.

С обзиром на то да се оружане снаге у свету убрзано окрећу ка беспилотним средствима, Турска би могла представљати предводника, нарочито ако се испостави да би БПЛ могле извршити све задатке ловаца бомбардера са људском посадом, али по много мањој цени коштања и са много мањим ризиком по људе.

Vučković, D., SAVREMENO NAORUŽANJE I VOJNA OPREMA / MODERN WEAPONS AND MILITARY EQUIPMENT, pp.816-836

Русија користи нови напредни противоклопни пројектил у Украјини[5]

Руски напредни противтенковски пројектил *LMUR* прошао је врло дугу развојну фазу, али је она, чини се, завршена.

Почетком јуна 2022. године, Русија је објавила видео-снимак са термалног трагача ракете на коме се види удар на неки сеоски објекат, наводно у Украјини. Затим су следили и други снимци. Неколико дана након објављивања првог снимка, руске новинске агенције су навеле да се ради о новом противоклопном пројектилу под називом *LMUR*. Истина је, ипак, мало компликованија.

LMUR

Интересантно је да се дефинитивно ради о термалном трагачу на ракети. Претходни снимци различитих руских ракетних удара по метама у Украјини увек су били снимљени са удаљених уређаја: са беспилотних летелица над бојиштем, са хеликоптерске осматрачке туреле или преко *CCTV* камера које би се налазиле близу места удара.

Русија има неколико врста оружја опремљених оптоелектронским трагачем који шаље слику командном месту или посади авиона. Ради се о лепези разних средстава, од малих система који су тешки само неколико килограма, као што је дрон камиказа или лутајућа муниција *Lancet,* па до озбиљнијег и тежег оружја, као што су различите верзије ракета *Kh-59M* и ракета ваздух-земља, масе до 907 кг.

Међутим, посматрајући лет ракете на видео-снимцима, као и тип и величину мета (једноспратне или двоспратне зграде), рекло би се да се

[5] www.thedrive July 28, 2022

ради о пројектилу средње величине. Највероватније је реч о пројектилу *LMUR*, или *izdeliye 305*, чија је маса нешто већа од 90 кг. На већини видео-снимака замућене су ознаке и натписи, али се понегде види натпис *AS-BPLA,* што такође указује на *LMUR*. Наиме, *AS-BPLA* је ознака комуникационе опреме пројектила *LMUR*.

Претпоставља се да је ово снимак са трагача пројектила LMUR који се приближава циљу негде у Украјини. Натпис IZL AS-BPLA, у горњем левом углу, вероватно означава „izlucheniye", што би значило – преноси преко комуникационог уређаја AS-BPLA.

Збуњујућа прошлост

Акроним пројекта *LMUR* појавио се током 2007. године у вези са лаким пројектилом корпорације *Korporatsiya Takticheskoye Raketnoye Vooruzheniye*(*KTRV)*. Међутим, убрзо после тога, око 2009. године, програм је напуштен из нејасних разлога.

Руско министарство одбране издало је, 22. фебруара 2011. године, наредбу за истраживање и развој кодног назива *Prifiks* у вези с развојем лаког вишенаменског вођеног пројектила *izdeliye 79*. Овог пута налог није додељен корпорацији *KTRV* већ компанији *Konstruktorskoye Byuro Mashinostroyeniya(KBM)*. Ова компанија је специјализована за противтенковске вођене ракете као што су *Ataka* или *Khrizantema,* али и балистичке ракете као што је *Iskander*.

Уговор је подразумевао израду, тестирање и припрему за серијску производњу ракете *LMUR izdeliye 79*. Током 2013. године произведена је серија за тестирање, али компанија *KBM* није могла започети тестове јер није било лансирног уређаја. Наиме, Министарство одбране једноставно није ни наручило развој лансирног уређаја. Након тога, компанија је формално поручила министарству да је престала са радом на том пројекту. Тек 2017. године, Министарство одбране Русије одлучује да прекине уговор. Након тога су уследиле серије тужби у вези с компензацијом, што је вероватно још у току.

Пројекат *LMUR* је ипак спасен, али другим пројектом о коме се врло мало зна. Претпоставља се да је 2012. године компанија *KBM* добила налог од Федералне обавештајне службе (ФСБ), правног следбеника совјетског КГБ-а, даразвије ракете под ознаком *izdeliye 305*. Наиме, ФСБ је тражио оружје дугог домета за свој специјални хеликоптер *Mi-8MNP-2 Hip*. Ови хеликоптери су коришћени за неконвенцијални рат на Кавказу. Ракета „305" је, у ствари, иста као и пројекат „79" која има двосмерни даталинк који преноси видео-снимак са трагача ракете у кокпит хеликоптера и преноси команде оператора ка ракети у лету. ФСБ је желео да има контролу над ракетом током целог њеног лета за случај да искрсне потреба за прекидом акције, односно лета ракете, уколико се испостави да је циљ погрешан.

Производни погон компаније Vympel у Москви где су приказани лансери за ракете LMUR, једноструке APU-305 (на крају) и двоструке APU-L (на почетку)

Овог пута лансер није заборављен, па је, заједно са *izdeliye 305*, наручен шински лансер *APU-305* од компаније *Toropov Vympel*. који је био намењен за једну ракету, док је касније та компанија израдила лансер за две ракете *APU-L.*

Тестирање ракета *LMUR* на хеликоптеру *Mi-8MNP-2* изведено је 2015. и 2016. године. Серијска производња почела је убрзо након тога и ракета је ушла у оперативну употребу на хеликоптерима ФСБ-а. Током 2019. године започели су тестови ракете *LMUR* на модернизованим хеликоптерима *Mi-28NM Havoc,* а нешто касније и на јуришним хеликоптерима *Ka-52M*. Обично су хеликоптери наоружани са по четири ракете на лансерима *APU-305*.

Двоструки шински лансер APU-L за ракете LMUR

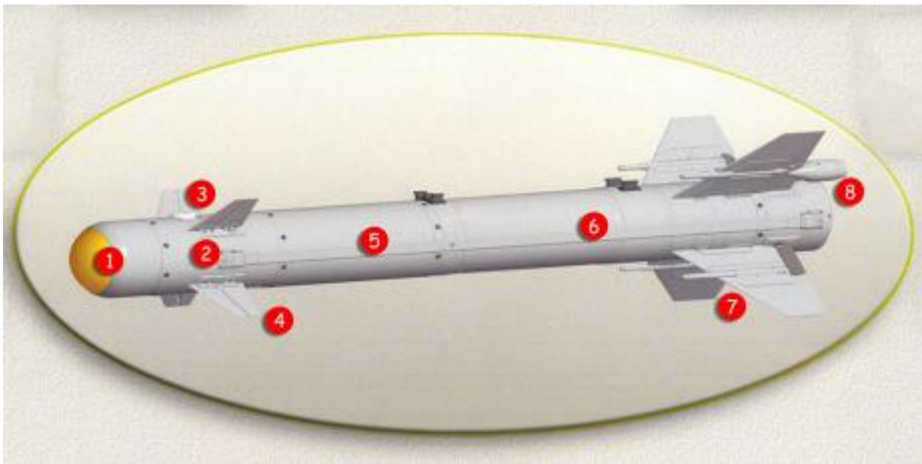
Оперативна употреба

Ознака *LMUR* потиче од *Lyogkaya Mnogotselevaya Upravlayemaya Raketa*, што би значило лака вишенаменска вођена ракета. Такође се означава са *305* или *305E* у извозној верзији. Иако се у опису ракете користи реч „лака”, она је два пута тежа од стандардних руских противоклопних вођених ракета, као што су *9M120 Ataka (AT-9 Spiral*) или *9M123 Khrizantema (AT-15 Springer*). Домет ракете *LMUR* је до 14,5 км, или два пута већи од претходних руских противтенковских вођених ракета.

Ракета има аеродинамичку конфигурацију са канардима и четири укрштена подељена пераја на предњој страни. Затим следи део са бојевом главом, а затим ракетни мотор са чврстим горивом. Велика укрштена крила

Vučković, D., SAVREMENO NAORUŽANJE I VOJNA OPREMA / MODERN WEAPONS AND MILITARY EQUIPMENT, pp.816-836

су склопљена, а отварају се када је ракета закачена за лансирни уређај на хеликоптеру.



Конфигурација ракете LMUR; 1 – термални трагач; 2 – аутопилот; 3 – пријемник сателитске навигације; 4 – контролна пераја; 5 – бојева глава; 6 – ракетни мотор; 7 – склопљена крила; 8 – даталинк антена

Тренажна верзија ракете, или *izdeliye 305-UL,* разликује се од борбене верзије по томе што има мања несклопива крила, без бојеве главе,

На предњој страни ракете налази се термални трагач *9B-7755* који је развио институт *MNITI* у Москви. Навигациони систем се састоји од инерцијалног аутопилота, радио-висинометра и сателитског навигационог пријемника *BNAP-305* са антеном на врху. Овај сателитски пријемник ради са руском сателитском мрежом *Glonass,* али и са западним сателитским мрежама. Два од четири крила опремљена су са даталинк антенама које су усмерене ка задњој страни ракете.

Не зна се много о страним компонентама које су уграђене у ракету *LMUR*. За сада је познато да ракета поседује електрично напајање компаније *Tesla Electric* и неке од чипова немачке компаније *Telefilter,* али их, без сумње, има још. Руски произвођачи наоружања сигурно имају потешкоћа са набавком стране опреме након све већег броја санкција Запада.

Најједноставнији начин употребе ракете *LMUR* је испаљивање на циљ који је у визуелном домету. Оператор у хеликоптеру види слику са трагача док је ракета још на подвесном лансеру и обележава циљ који трагач памти. Након што је ракета лансирана, хеликоптер може напустити место испаљивања јер се ракета затим аутоматски сама наводи на циљ док га не погоди.

Други начин, први пут употребљен на руским противоклопним вођеним ракетама, јесте испаљивање ракете на невидљив циљ ван визуелног

VOJNOTEHNIČKI GLASNIK / MILITARY TECHNICAL COURIER, 2023, Vol. 71, Issue 3

домета. Прво, ракета лети до региона циља вођена инерцијалним аутопилотом са корекцијама омогућеним сателитском навигацијом.

Слика са трагача преноси се у кокпит хеликоптера путем даталинка, а команде навођења се затим преносе на ракету. Оператор у хеликоптеру гледа промене, бира циљ и то преноси ракети, а може променити циљ или поништити наредбу. На једном снимку је могуће видети како се ознака циља мења у односу на другу зграду неколико секунди пре удара.

Ради успешне комуникације са ракетом, хеликоптер мора бити опремљен одговарајућом опремом. Овај систем је *AS-BPLA (Apparatura Svyazi s Bespilotnym Letatelnym Apparatom*), што би значило комуникациона опрема са беспосадном ваздушном летелицом. Систем је развила компанија KB Luch, а постоји у неколико верзија. Двосмерни даталинк ради на S-таласима (фреквенције 2–4 GHz ; таласне дужине 7,5–15 цм), има декласирану таласну брзину од 5,4 Mbps и домет од 50 км.

На хеликоптеру Ка-52М комуникациони контејнер има облик капље и окачен је испод десног крила. На хеликоптеру Mi-8MNP-2, радио-даталинк антена налази се на лоптастом додатку у носу хеликоптера, као и на хеликоптеру Mi-28NE. Слична опрема налази се и на новијем хеликоптеру Mi-28NM, а решење је слично као код хеликоптера Ka-52M.

Пробни хеликоптер Ка-52 са ракетом LMUR

Vučković, D., SAVREMENO NAORUŽANJE I VOJNA OPREMA / MODERN WEAPONS AND MILITARY EQUIPMENT, pp.816-836

Лоптасти део на носу хеликоптера Mi-28NE носи даталинк AS-BPLA за комуникацију са ракетом LMUR

Недоумице

С једне стране, употреба ракете *LMUR* у Украјини не представља никакво изненађење. Ракета је у производњи већ неколико година, па се претпоставља да је руском министарству одбране испоручено бар 200 комада, а известан број и руском ФСБ-у.

То оружје није јефтино. На основу података из уговора из 2018. године, једна ракета *LMUR* кошта око 227.000 долара. Ради се о цени за руско министарство одбране, док је за извозне примерке сигурно већа.

Међутим, примећено је неколико необичних чињеница. Наиме, сви видео-снимци који су приказивали употребу ракете *LMUR* у Украјини направљени су термалном камером трагача ракете. Не постоји ниједан снимак ракете са хеликоптера, а такође није било могуће видети ниједан хеликоптер опремљен контејнером са даталинком.

Неке од мета су такође чудне. Ради се о различитим зградама или баракама од којих неке изгледају напуштене. На једном снимку зграда нема ни кров.

Уколико су ракете *LMUR* употребљене у Украјини, највероватнија лансирна платформа је *Mi-8MNP-2,* хеликоптер који користе специјалне снаге руског ФСБ-а. Хеликоптери *Mi-28NM* и *Ka-52M* који имају могућност употребе ракете *LMUR* још нису у оперативној употреби у ваздухопловним снагама Русије у Украјини.

Први модернизовани хеликоптер Ка-52М опремљен контејнером са даталинком AS-BPLA (1) и шинским лансером APU-305 (2) за ракете LMUR

Ипак, постоји још једна опција. Пре пет година рађено је истраживање и пројектовање пројекта под називом *Baikal* у оквиру кога је планирано адаптирање ракете *LMUR* за употребу у копненом лансеру на оклопном возилу. Није познато како се овај пројекат завршио, али је могуће да су нека возила опремљена овим системом и испробана у Украјини.

Пројекат Baikal

Јасно је да постоје многе недоумице у вези с ракетом *LMUR*. То је важан програм за руску армију јер Русија поседује само старије генерације вођених противоклопних ракета које знатно заостају за западним решењима.

Спецификације ракете *LMUR (izdeliye 305E)*:

Максималан домет	14,5 км
Максимална брзина	230 м/с
Висина лета	100-600 м
Маса	105 кг
Бојева глава	25 кг
Дужина	1,945 мм
Дијаметар	200 мм

Драган М. Вучковић (*Dragan* M. Vučković),
e-mail: draganvuckovic64@gmail.com,
ORCID iD: https://orcid.org/0000-0003-1620-5601

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 рецензирани научни часопис.

Власници часописа су Министарство одбране Републике Србије и Војска Србије. Издавач и финансијер часописа је Универзитет одбране у Београду (Војна академија).

Програмска оријентација часописа заснива се на годишњој категоризацији часописа, коју врши надлежно државно министарство у одређеним областима, као и на његовом индексирању у међународним индексним базама.

Часопис обухвата научне, односно стручне области у оквиру образовно-научног поља **природно-математичких наука**, као и у оквиру образовно-научног поља **техничко-технолошких наука**, а нарочито области **одбрамбених наука и технологија**. Објављује теоријска и практична достигнућа која доприносе усавршавању свих припадника српске, регионалне и међународне академске заједнице, а посебно припадника војски и министарстава одбране. Публикује радове са уравнотеженим извештавањем о аналитичким, експерименталним и примењеним истраживањима, као и нумеричким симулацијама, обухватајући различите дисциплине. Објављени материјали су високог квалитета и релевантности, написани на начин који их чини доступним широкој читалачкој публици. Сви радови који извештавају о оригиналним теоријским и/или практично оријентисаним истраживањима или проширеним верзијама већ објављених радова са конференција су добродошли. Радови за објављивање одабиру се двоструко слепим поступком рецензије како би се осигурала оригиналност, релевантност и читљивост. Притом циљ није само да се квалитет објављених радова одржи високим већ и да се обезбеди правовремени, темељни и уравнотежени поступак рецензије.

Уређивачка политика *Војнотехничког гласника* заснива се на препорукама Одбора за етичност у издаваштву (COPE Core Practices) и заједничким принципима транспарентности и најбоље праксе у издаваштву COPE, DOAJ, OASPA и WAME, као и на најбољим прихваћеним праксама у научном издаваштву. *Војнотехнички гласник* је члан COPE (Committee on Publication Ethics) од 2. маја 2018. године и члан OASPA (Open Access Scholarly Publishers Association) од од 27. новембра 2015. године.

Министарство просвете, науке и технолошког развоја Републике Србије утврдило је дана 25. 10. 2022. године категоризацију *Војнотехничког гласника*, за 2022. годину:

– **на листи часописа за рачунарске науке:**
категорија врхунски часопис националног значаја **(М51)**,
– **на листи часописа за електронику, телекомуникације и информационе технологије:**
категорија врхунски часопис националног значаја **(М51)**,
– **на листи часописа за машинство:**
категорија врхунски часопис националног значаја **(М51)**,
– **на листи часописа за материјале и хемијске технологије:**
категорија врхунски часопис националног значаја **(М51)**.

Усвојене листе домаћих часописа за 2022. годину могу се видети на сајту *Војнотехничког гласника*, страница *Категоризација часописа*.

Детаљније информације могу се пронаћи и на сајту Министарства просвете, науке и технолошког развоја Републике Србије.

Подаци о категоризацији могу се пратити и на сајту КОБСОН-а (Конзорцијум библиотека Србије за обједињену набавку).

Категоризација часописа извршена је према Правилнику о категоризацији и рангирању научних часописа Министарства просвете, науке и технолошког развоја Републике Србије ("Службени гласник РС", број 159/20).

Часопис се прати у контексту Српског цитатног индекса – СЦиндекс (база података домаћих научних часописа), Научно-информационог система Redalyc и Руског индекса научног цитирања (РИНЦ). Подвргнут је сталном вредновању (мониторингу) у зависности од утицајности (импакта) у самим базама. Детаљи о индексирању могу се видети на сајту *Војнотехничког гласника*, страница *Индексирање часописа*.

Војнотехнички гласник, у погледу свог садржаја, пружа могућност отвореног приступа (DIAMOND OPEN ACCESS) 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 (мотивацију за рад), разраду (адекватан преглед репрезентативности рада у његовој области, јасну изјаву о новини у представљеном истраживању, одговарајућу теоријску позадину, један или више примера за демонстрирање и дискусију о представљеним идејама), закључак и литературу (без нумерације наслова и поднаслова). Обим чланка треба да буде до 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).

Пожељно је да обим кратких саопштења буде 4 до 7 страница, научних чланака и студија случаја 10 до 14 страница, док прегледни радови могу бити и дужи. Број страница није строго ограничен и, уз одговарајуће образложење, пријављени чланци такође могу бити дужи или краћи.

Ако су радови који су претходно објављени на конференцији проширени, уредници ће проверити да ли је додато довољно новог материјала који испуњава стандарде часописа и квалификује поднесак за поступак рецензије. Додати материјал не сме бити претходно објављен. Нови резултати нису нужно потребни, али су пожељни. Међутим, поднесак треба да садржи проширене кључне идеје, примере, разраде, итд., који су претходно били садржани у поднеску са конференције.

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

Адреса редакције:
Војнотехнички гласник
Вељка Лукића Курјака 33
11042 Београд
e-mail: vojnotehnicki.glasnik@mod.gov.rs.
тел: војни 40-260 (011/3603-260), 066/8700-123

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 рецензируемым научным журналом.

Собственники журнала: Министерство обороны и Вооруженые силы Республики Србия.

Издатель журнала: Университет обороны в г. Белград (Военная академия).

Программная ориентация журнала основана на ежегодной категоризации журнала, которая производится соответствующим отраслевым министерством, в зависимости от области исследований, а также на его индексировании в международных наукометрических базах данных.

Журнал охватывает научные и профессиональные сферы в рамках учебно-научной области **естественно-математических наук**, а также в рамках учебно-научной области **технико-технологических наук**, особенно в области **оборонных наук и технологии**. В журнале публикуются теоретические и практические достижения, которые способствуют повышению квалификации представителей сербского, регионального и международного академического сообщества, особенно служащих Министерств Обороны и Вооружённых сил. В журнале публикуются статьи со соответствующими обзорами об аналитических, экспериментальных и прикладных исследованиях, а также о численном моделировании, охватывая различные дисциплины. Публикуемые материалы отличаются высоким качеством и актуальностью. Они написаны научным, но понятным и доступным для широкого круга читателей языком. Приветствуются все статьи, сообщающие об оригинальных теоретических и/или практических исследованиях и/или расширенные версии ранее опубликованных статей, представленных на конференциях. Статьи для публикации отбираются путем двойного слепого рецензирования, которое гарантирует оригинальность, актуальность и удобочитаемость. Цель состоит не только в поддержании высокого качества публикуемых статей, но и в обеспечении своевременного, тщательного и соответствующего процесса рецензирования.

Редакционная политика журнала *«Военно-технический вестник»* основана на рекомендациях Комитета по этике научных публикаций (COPE Core Practices), общих принципах прозрачности и лучшей практике издательской деятельности COPE, DOAJ, OASPA и WAME, а также на лучшей практике научно-издательской деятельности. Журнал *«Военно-технический вестник»* является членом COPE (Комитет по этике научных публикаций) со 2 мая 2018 года и членом OASPA (Ассоциация научных издателей открытого доступа) с 27 ноября 2015 года.

Министерством образования, науки и технологического развития Республики Сербия утверждена 25 октября 2022 г. категоризация журнала *«Военно-технический вестник»* за 2022 год:

- **Область компьютерные науки:**
  ведущий журнал государственного значения **(М51)**,
- **Область электроники, телекоммуникаций и информационных технологий:**
  ведущий журнал государственного значения **(М51)**,
- **Область машиностроения:**
  ведущий журнал государственного значения **(М51)**,
- **Область материалов и химической технологии:**
  ведущий журнал государственного значения **(М51)**.

С информацией относительно категоризации за 2022 год можно ознакомиться на странице сайта *«Военно-технического вестника» Категоризация Вестника*.

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)

Журнал соответствует стандартам Сербского индекса научного цитирования (СЦИндекс/SCIndeks) - наукометрической базы данных научных журналов Республики Сербия, Научно-информационного система Redalyc, а также Российского индекса научного цитирования (РИНЦ). Журнал постоянно подвергается мониторингу и оценивается количественными наукометрическими показателями отражающими его научную ценность.

С информацией об индексировании можно ознакомиться на странице сайта журнала *Индексирование Вестника*.

«Военно-технический вестник» относительно своего содержания предоставляет пользователям возможность открытого доступа (DIAMOND OPEN ACCESS) и положениями об авторских правах, утвержденными Creative Commons (CC BY). С инструкцией об авторских правах можно ознакомиться на странице сайта журнала *Авторские права и политика самоархивирования*.

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 (цель исследования), основную часть (соответствующий обзор представительного исследования в данной области, четкое изложение научной новизны в представленном исследовании, соответствующую теоретическую основу, один или несколько примеров для демонстрирования и обсуждения представленных тезисов), заключение и список литературы (без нумерации заголовков и подзаголовков). Объем статьи не должен превышать один авторский лист (16 страниц формата А4 с одинарным интервалом, максимум до 24 страниц, включая ссылки и приложения). 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.).

Объем кратких сообщений составляет 4-7 страниц, исследовательские статьи и тематические исследования с проблемно-ситуационным анализом − 10-14 страниц, однако объем обзорных статей может быть больше. Ограничения по количеству страниц не являются строгими, следовательно при соответствующем обосновании предоставленные работы могут быть длиннее или короче. В случае подачи расширенных версий ранее опубликованных докладов, представленных на конференции, редакция проверит было ли добавлено достаточно новых материалов для того, чтобы статья соответствовала стандартам журнала и условиям рецензирования. Добавленный материал должен быть новым, неопубликованным ранее. Новые результаты приветствуются, но не являются обязательным условием; однако ключевые тезисы, примеры, разработки и пр. должны быть более подробно представлены в статье по сравнению с первичным докладом на конфереции.

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

Почтовый адрес редакции:

«Војнотехнички гласник»
ул. Велька Лукича Куряка 33, 11042 Белград, Республика Сербия
e-mail: vojnotehnicki.glasnik@mod.gov.rs,
тел: +381 11 3603 260, +381 66 8700 123

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 an peer-reviewed scientific journal.

The owners of the journal are the Ministry of Defence of the Republic of Serbia and the Serbian Armed Forces. The publisher and financier of the *Military Technical Courier* is the University of Defence in Belgrade (Military Academy).

The program of the journal is based on the annual classification of journals performed by a relevant Ministry as well as on its indexing in international indexing databases.

The journal covers scientific and professional fields within the educational-scientific field of **Natural-Mathematical Sciences**, as well as within the educational-scientific field of **Technical-Technological Sciences**, and especially the field of **defense sciences and technologies**. It publishes 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. It publishes papers with balanced coverage of analytical, experimental, and applied research as well as numerical simulations from various disciplines. The material published is of high quality and relevance, written in a manner that makes it accessible to a wider readership. The journal welcomes papers reporting original theoretical and/or practice-oriented research as well as extended versions of already published conference papers. Manuscripts for publication are selected through a double-blind peer-review process to validate their originality, relevance, and readability. This being so, the objective is not only to keep the quality of published papers high but also to provide a timely, thorough, and balanced review process.

The editorial policy of the *Military Technical Courier* is based on the COPE Core Practices, common COPE, DOAJ, OASPA and WAME Principles of Transparency and Best Practice in Scholarly Publishing as well as on the best accepted practices in scientific publishing. The Military Technical Courier has been a COPE (Committee on Publication Ethics) member since 2nd May 2018 and a member of OASPA (Open Access Scholarly Publishers Association) since 27th November 2015.

The Ministry of Education, Science and Technological Development of the Republic of Serbia classified the *Military Technical Courier* for the year 2022, on October 25, 2022

– **on the list of periodicals for computer sciences,**
  category: reputed national journal **(M51)**,
– **on the list of periodicals for electronics, telecommunications and IT,**
  category: reputed national journal **(M51)**,
– **on the list of periodicals for mechanical engineering,**
  category: reputed national journal **(M51)**,
– **on the list of periodicals for materials and chemical technology,**
  category: reputed national journal **(M51)**.

The approved lists of national periodicals for the year 2022 can be viewed on the website of the *Military Technical Courier*, page *Journal categorization*.

More detailed information can be found on the website of the Ministry of Education, Science and Technological Development of the Republic of Serbia.

The information on the categorization can be also found on the website of KOBSON (Consortium of Libraries of Serbia for Unified Acquisition).

The periodical is categorized in compliance with the Regulations on 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.

The journal is in the Serbian Citation Index – SCIndex (data base of national scientific journals), in the Scientific Information System Redalyc, and 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. More detailed information can be viewed on the website of the *Military Technical Courier*, page *Journal indexing*.

The *Military Technical Courier*, in terms of its content, offers the possibility of open access (DIAMOND OPEN ACCESS) and applies the Creative Commons Attribution (CC BY) licence on copyright. The copyright details can be found on the *Copyright notice and Self-archiving policy* page of the journal's website.

Manuscripts are submitted online, through the electronic editing system ASSISTANT, developed by the Center for Evaluation in Education and Science – CEON.

The access and the registration are through the *Military Technical Courier* site http://www.vtg.mod.gov.rs/index-e.html, on the page *ASSISTANT* or the page *SCINDEKS* or directly through the link (aseestant.ceon.rs/index.php/vtg).

The detailed instructions about the registration for the service are on the website http://www.vtg.mod.gov.rs/index-e.html, on the page *Instructions for ASSISTANT*.

All authors submitting a manuscript for publishing in the *Military Technical Courier* should register for an ORCID ID following the instructions on the web page *Registration for an ORCID identifier*.

The *Military Technical Courier* publishes articles in English, using Arial and a font size of 11pt with Single Spacing.

The procedures of article preparation, writing and editing should be in accordance with the *Publication ethics statement* (http://www.vtg.mod.gov.rs/publication-ethics-statement.html).

The article should contain an abstract with keywords, introduction (motivation for the work), body (adequate overview of the representative work in the field, a clear statement of the novelty in the presented research, suitable theoretical background, one or more examples to demonstrate and discuss the presented ideas), conclusion, and references (without heading and subheading enumeration). The article length should not normally exceed 16 pages of the A4 paper format with single spacing, up to a maximum of 24 pages with references and supplementary material included.

The article should be formatted following the instructions in the Article Form which can be downloaded from website page *Article form*.

Title

The title should be informative. It is in both Journal's and author's best interest to use terms suitable for indexing and word search. If there are no such terms in the title, the author is strongly advised to add a subtitle.

Letterhead title

The letterhead title is given at a top of each page for easier identification of article copies in an electronic form in particular. It contains the author's surname and first name initial (for multiple authors add "et al"), article title, journal title and collation (year, volume, issue, first and last page). The journal and article titles can be given in a shortened form.

Author's name

Full name(s) of author(s) should be used. It is advisable to give the middle initial. Names are given in their original form (with diacritic signs if in Serbian).

Author's affiliation

The full official name and seat of the author's affiliation is given, possibly with the name of the institution where the research was carried out. For organizations with complex structures, give the whole hierarchy (for example, University of Defence in Belgrade, Military Academy, Department for Military Electronic Systems). At least one organization in the hierarchy must be a legal entity. When some of multiple authors have the same affiliation, it must be clearly stated, by special signs or in other way, which department exactly they are affiliated with. The affiliation follows the author's name. The function and title are not given.

Contact details

The postal addresses or the e-mail addresses of the authors are given in the first page.

Type of articles

Classification of articles is a duty of the editorial staff and is of special importance. Referees and the members of the editorial staff, or section editors, can propose a category, but the editor-in-chief has the sole responsibility for their classification.

Journal articles are classified as follows:

Scientific articles:

– Original scientific papers (giving the previously unpublished results of the author's own research based on scientific methods);

– Review papers (giving an original, detailed and critical view of a research problem or an area to which the author has made a contribution demonstrated by self-citation);

– Short communications or Preliminary communications (original scientific full papers but shorter or of a preliminary character);

– Scientific commentaries or discussions (discussions on a particular scientific topic, based exclusively on scientific argumentation) and opinion pieces.

Exceptionally, in particular areas, a scientific paper in the Journal can be in a form of a monograph or a critical edition of scientific data (historical, archival, lexicographic, bibliographic, data survey, etc.) which were unknown or hardly accessible for scientific research.

Papers classified as scientific must have at least two positive reviews.

If the journal contains non-scientific contributions as well, the section with scientific papers should be clearly denoted in the first part of the Journal.

Professional articles:

– Professional papers (contributions offering experience useful for improvement of professional practice but not necessarily based on scientific methods);

– Informative contributions (editorial, commentary, etc.);

– Reviews (of a book, software, case study, scientific event, etc.)

Short communications are usually 4-7 pages long, research articles and case studies 10-14 pages, while reviews can be longer. Page number limits are not strict and, with appropriate reasoning, submitted manuscripts can also be longer or shorter. If extended versions of previously published conference papers are submitted, Editors will check if sufficient new material has been added to meet the journal standards and to qualify such manuscripts for the review process. The added material must not have been previously published. New results are desired but not necessarily required; however, submissions should contain expansions of key ideas, examples, elaborations, etc. of conference papers.

Language

The language of the article should be in English. The grammar and style of the article should be of good quality. The systematized text should be without abbreviations (except standard ones). All measurements must be in SI units. The sequence of formulae is denoted in Arabic numerals in parentheses on the right-hand side.

Abstract and summary

An abstract is a concise informative presentation of the article content for fast and accurate evaluation of its relevance. It contains the terms often used for indexing and article search. A 100- to 250-word abstract has the following parts: introduction/purpose of the research, methods, results and conclusion.

Keywords

Keywords are terms or phrases showing adequately the article content for indexing and search purposes. They should be allocated heaving in mind widely accepted international sources (index, dictionary or thesaurus), such as the Web of Science keyword list for science in general. The higher their usage frequency is, the better. Up to 10 keywords immediately follow the abstract and the summary, in respective languages. For this purpose, the ASSISTANT system uses a special tool KWASS for the automatic extraction of key words from disciplinary thesauruses/dictionaries by choice and the routine for their selection, i.e. acceptance or rejection by author and/or editor.

Article acceptance date

The date of the reception of the article, the dates of submitted corrections in the manuscript (optional) and the date when the Editorial Board accepted the article for publication are all given in a chronological order at the end of the article.

Acknowledgements

The name and the number of the project or programme within which the article was realised is given in a separate note at the bottom of the first page together with the name of the institution which financially supported the project or programme.

Article preliminary version

If an article preliminary version has appeared previously at a meeting in a form of an oral presentation (under the same or similar title), this should be stated in a separate note at the bottom of the first page. An article published previously cannot be published in the *Military Technical Courier* even under a similar title or in a changed form.

Tables and illustrations

All the captions should be in the original language as well as in English, together with the texts in illustrations if possible. Tables are typed in the same style as the text and are denoted by Arabic numerals at the top. Photographs and drawings, placed appropriately in the text, should be clear, precise and suitable for reproduction. Drawings should be created in Word or Corel.

For figures and graphs, proper data plot is recommended i.e. using a data analysis program such as Excel, Matlab, Origin, SigmaPlot, etc. It is not recommended to use a screen capture of a data acquisition program as a figure or a graph.

Citation in the text

Citation in the text must be uniform. The *Military Technical Courier* applies the Harvard Referencing System given in the Harvard Style Manual. When citing sources within your paper, i.e. for in-text references of the works listed at the end of the paper, place the year of publication of the work in parentheses and optionally the number of the page(s) after the author's name, e.g. (Petrovic, 2012, pp.10-12). A detailed guide on citing, with examples, can be found on *Military Technical Courier* website on the page *Instructions for Harvard Style Manual*. In-text citations should follow its guidelines. For checking in-text citations, the ASSISTANT system uses a special tool CiteMatcher to find out quotes left out within papers and in reference lists.

Footnotes

Footnotes are given at the bottom of the page with the text they refer to. They can contain less relevant details, additional explanations or used sources (e.g. scientific material, manuals). They cannot replace the cited literature.

Reference list (Literature)

The cited literature encompasses bibliographic sources such as articles and monographs and is given in a separate section in a form of a reference list. References are not translated to the language of the article.

In compiling the reference list and bibliography, the *Military Technical Courier* applies the Harvard System – Harvard Style Manual. All bibliography items should be listed alphabetically by author's name, without numeration. A detailed guide for listing references, with examples, can be found on *Military Technical Courier* website on the page *Instructions for Harvard Style Manual*. Reference lists at the end of papers should follow its guidelines. In journal evaluation systems, non-standard, insufficient or inconsequent citation is considered to be a sufficient cause for denying the scientific status to a journal.

Authorship Statement

The Authorship statement, submitted together with the paper, states authors' individual contributions to the creation of the paper. In this statement, the authors also confirm that they followed the guidelines given in *the Call for papers* and the *Publication ethics and malpractice statement of the journal*.

All articles are peer reviewed.

The list of referees of the *Military Technical Courier* can be viewed at website page *List of referees*. The article review process is described on the *Peer Review Process* page of the website.

Editorial Team

Address of the Editorial Office:
Vojnotehnički glasnik / Military Technical Courier
Veljka Lukića Kurjaka 33
11042 Belgrade, Republic of Serbia
e-mail: vojnotehnicki.glasnik@mod.gov.rs, tel.: +381 11 3603 260, +381 66 8700 123

Ликовно-графички уредник
Марија Марић, e-mail: marija.maric@mod.gov.rs

Лектор
Добрила Милетић, e-mail: miletic.dobrila@gmail.com

Превод на енглески
Јасна Вишњић, e-mail: jasnavisnjic@yahoo.com

Превод на руски
Др *Карина* Авагјан, e-mail: karinka2576@mail.ru

CIP – Каталогизација у публикацији
Народна библиотека Србије, Београд

623+355/359

ВОЈНОТЕХНИЧКИ гласник : научни часопис Министарства одбране и Војске Србије = Военно-технический вестник : научный журнал Министерства обороны и Вооружённых сил Республики Сербия = Military Technical Courier : scientific Journal of the Ministry of Defence and the Serbian Armed Forces / главни и одговорни уредник Драган Памучар. - Год. 1, бр. 1 (1. јан. 1953)- . - Београд : Универзитет одбране у Београду, Војна академија, 1953- (Београд : Војна штампарија). - 23 cm

Тромесечно. - Текст на срп., рус. и енгл. језику. - Друго издање на другом медијуму: Vojnotehnički glasnik (Online) = ISSN 2217-4753
ISSN 0042-8469 = Војнотехнички гласник
COBISS.SR-ID 4423938

Цена: 600,00 динара

Тираж: 100 примерака

На основу мишљења Министарства за науку, технологију и развој Републике Србије, број 413-00-1201/2001-01 од 12. 9. 2001. године,
часопис „Војнотехнички гласник“ је публикација од посебног интереса за науку.

УДК: Народна библиотека Србије, Београд

Адреса редакције: Војнотехнички гласник,
Вељка Лукића Курјака 33, 11042 Београд

http://www.vtg.mod.gov.rs
http://aseestant.ceon.rs/index.php/vtg/issue/current
http://scindeks.nb.rs/journaldetails.aspx?issn=0042-8469
https://www.redalyc.org/revista.oa?id=6617
http://elibrary.ru/title_about.asp?id=53280
https://doaj.org/toc/2217-4753

Војнотехнички гласник је лиценциран код EBSCO Publishing-a.
Комплетан текст *Војнотехничког гласника* доступан је у базама података EBSCO Publishing-a.

e-mail: vojnotehnicki.glasnik@mod.gov.rs
Twitter: @MilTechCourier

Претплата на штампано издање: e-mail: vojnotehnicki.glasnik@mod.gov.rs; тел. 066/87-00-123.

Часопис излази тромесечно.

Први штампани број *Војнотехничког гласника* објављен је 1. 1. 1953. године.

Прво електронско издање *Војнотехничког гласника* на Интернету објављено је 1. 1. 2011. године.

Штампа: Војна штампарија – Београд, Ресавска 40б, e-mail: vojna.stamparija@mod.gov.rs

Художественный редактор
Мария Марич, e-mail: marija.maric@mod.gov.rs

Корректор
Добрила Милетич, e-mail: miletic.dobrila@gmail.com

Перевод на английский язык
Ясна Вишнич, e-mail: jasnavisnjic@yahoo.com

Перевод на русский язык
Д.филол.н. *Карина* Кареновна Авагян, e-mail: karinka2576@mail.ru

CIP – Каталогизация в публикации
Национальная библиотека Сербии, г. Белград

623+355/359

ВОЈНОТЕХНИЧКИ гласник : научни часопис Министарства одбране
и Војске Србије = Военно-технический вестник : научный журнал
Министерства обороны и Вооружённых сил Республики Сербия =
Military Technical Courier : scientific Journal of the Ministry of Defence and the Serbian
Armed Forces / главни и одговорни уредник Драган Памучар. -
Год. 1, бр. 1 (1. јан. 1953)- . - Београд : Универзитет одбране у Београду,
Војна академија, 1953- (Београд : Војна штампарија). - 23 cm

Тромесечно. - Текст на срп., рус. и енгл. језику. - Друго издање
на другом медијуму: Vojnotehnički glasnik (Online) = ISSN 2217-4753
ISSN 0042-8469 = Војнотехнички гласник
COBISS.SR-ID 4423938

Цена: 600,00 динаров

Тираж: 100 экземпляров

На основании решения Министерства науки и технологий Республики Сербия,
№ 413-00-1201/2001-01 от 12. 9. 2001 года, журнал «Военно-технический вестник»
объявлен изданием, имеющим особое значение для науки.

УДК: Национальная библиотека Сербии, г. Белград

Адрес редакции: Војнотехнички гласник,
Ул. Велька Лукича Куряка 33, 11042 Белград, Республика Сербия

http://www.vtg.mod.gov.rs
http://aseestant.ceon.rs/index.php/vtg/issue/current
http://scindeks.nb.rs/journaldetails.aspx?issn=0042-8469
https://www.redalyc.org/revista.oa?id=6617
http://elibrary.ru/title_about.asp?id=53280
https://doaj.org/toc/2217-4753

«Военно-технический вестник» включен в систему EBSCO. Полный текст журнала
«Военно-технический вестник» можно найти в базах данных EBSCO Publishing.

e-mail: vojnotehnicki.glasnik@mod.gov.rs
Twitter: @MilTechCourier

Подписка на печатную версию журнала: e-mail: vojnotehnicki.glasnik@mod.gov.rs;
тел. +381 66 87 00 123.

Журнал выпускается ежеквартально.

Первый номер журнала «Военно-технический вестник» выпущен 1.1.1953 года.

Первая электронная версия журнала размещена на интернет странице 1.1.2011 года.

Типография: Војна штампарија – Белград, Ресавска 40б, e-mail: vojna.stamparija@mod.gov.rs

Graphic design editor
Marija Marić, e-mail: marija.maric@mod.gov.rs

Proofreader
Dobrila Miletić, e-mail: miletic.dobrila@gmail.com

English translation and polishing
Jasna Višnjić, e-mail: jasnavisnjic@yahoo.com

Russian translation and polishing
Dr. *Karina* Avagyan, e-mail: karinka2576@mail.ru

CIP – Catalogisation in the publication
National Library of Serbia, Belgrade

623+355/359

ВОЈНОТЕХНИЧКИ гласник : научни часопис Министарства одбране и Војске Србије = Военно-технический вестник : научный журнал Министерства обороны и Вооружённых сил Республики Сербия = Military Technical Courier : scientific Journal of the Ministry of Defence and the Serbian Armed Forces / главни и одговорни уредник Драган Памучар. - Год. 1, бр. 1 (1. јан. 1953)- . - Београд : Универзитет одбране у Београду, Војна академија, 1953- (Београд : Војна штампарија). - 23 cm

Тромесечно. - Текст на срп., рус. и енгл. језику. - Друго издање на другом медијуму: Vojnotehnički glasnik (Online) = ISSN 2217-4753
ISSN 0042-8469 = Војнотехнички гласник
COBISS.SR-ID 4423938

Price: 600.00 RSD

Printed in 100 copies

According to the Opinion of the Ministry of Science and Technological Development No 413-00-1201/2001-01 of 12th September 2001, the *Military Technical Courier* is a publication of special interest for science.

UDC: National Library of Serbia, Belgrade

Address: Vojnotehnički glasnik/Military Technical Courier,
Veljka Lukića Kurjaka 33, 11042 Belgrade, Republic of Serbia

http://www.vtg.mod.gov.rs/index-e.html
http://aseestant.ceon.rs/index.php/vtg/issue/current
http://scindeks.nb.rs/journaldetails.aspx?issn=0042-8469
https://www.redalyc.org/revista.oa?id=6617
http://elibrary.ru/title_about.asp?id=53280
https://doaj.org/toc/2217-4753

Military Technical Courier has entered into an electronic licensing relationship with EBSCO Publishing. The full text of *Military Technical Courier* can be found on EBSCO Publishing's databases.

e-mail: vojnotehnicki.glasnik@mod.gov.rs
Twitter: @MilTechCourier

Subscription to print edition: e-mail: vojnotehnicki.glasnik@mod.gov.rs; Tel. +381 66 87 00 123.

The journal is published quarterly.

The first printed issue of the *Military Technical Courier* appeared on 1st January 1953.
The first electronic edition of the *Military Technical Courier* on the Internet appeared on 1st January 2011.

Printed by Vojna štamparija – Belgrade, Resavska 40b, e-mail: vojna.stamparija@mod.gov.rs

ВТГ
ОД 1953.
ГОДИНА

VTG
OD 1953.
GODINA

ВТБ
С 1953 г.
ЛЕТ

MTG
SINCE 1953
YEARS