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

Вол. 70, бр. 1
2022

70 ОД 1953. ГОДИНА

НАУЧНИ ЧАСОПИС МИНИСТАРСТВА ОДБРАНЕ И ВОЈСКЕ СРБИЈЕ

ВОЈНОТЕХНИЧКИ ГЛАСНИК

1 2022 ВОЈНОТЕХНИЧКИ ГЛАСНИК

ВТГ.МО.УПР.СРБ

www.vtg.mod.gov.rs

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

Том 70, № 1
2022

ВТГ

70 С 1953 г. ЛЕТ

НАУЧНЫЙ ЖУРНАЛ МИНИСТЕРСТВА ОБОРОНЫ
И ВООРУЖЕННЫХ СИЛ РЕСПУБЛИКИ СЕРБИЯ

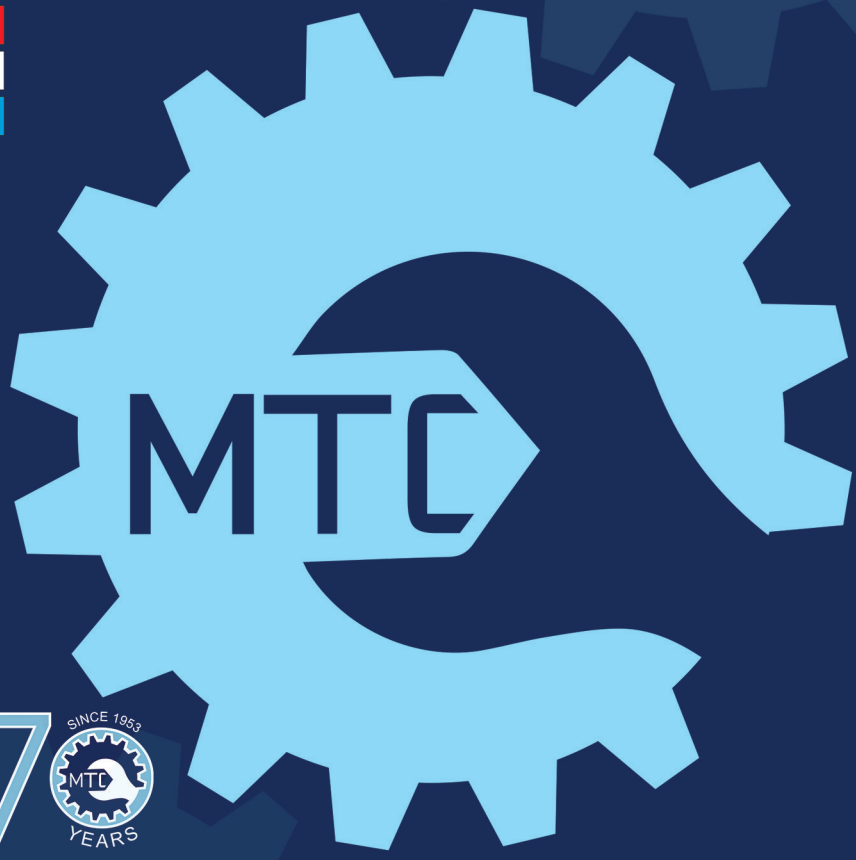
ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК

ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК
1 2022

ВТГ.МО.УПР.СРБ
www.vtg.mod.gov.rs

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

Vol. 70, Issue 1
2022



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

MILITARY TECHNICAL COURIER

MILITARY TECHNICAL COURIER
1 2022

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 70 • БРОЈ 1 • ЈАНУАР – МАРТ 2022.

NAUČNI ČASOPIS MINISTARSTVA ODBRANE I VOJSKE SRBIJE

VOJNOTEHNIČKI GLASNIK

VOLUMEN 70 • BROJ 1 • JANUAR – MART 2022.

втг.мо.упр.срб
www.vtg.mod.gov.rs
COBISS.SR-ID: 4423938
COBISS.SR-ID: 181287436
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 70 • НОМЕР ВЫПУСКА 1 • ЯНВАРЬ-МАРТ 2022.

SCIENTIFIC JOURNAL OF THE MINISTRY OF DEFENCE AND SERBIAN ARMED FORCES

MILITARY TECHNICAL COURIER

VOLUME 70 • ISSUE 1 • JANUARY-MARCH 2022

ВТГ.МО.УПР.СРБ
www.vtg.mod.gov.rs
COBISS.SR-ID: 4423938
COBISS.SR-ID: 181287436
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

APPLICATION OF PROBABILITY-BASED MULTI–OBJECTIVE OPTIMIZATION IN MATERIAL ENGINEERING

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

DOI: 10.5937/vojtehg70-35366; https://doi.org/10.5937/vojtehg70-35366

FIELD: Mathematics, Materials
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: Althought many methods have been proposed to deal with the problem of material selection, there are inherent defects of additive algorithms and subjective factors in such methods. Recently, a probability-based multi–objective optimization was developed to solve the inherent shortcomings of the previous methods, which introduces a novel concept of preferable probability to reflect the preference degree of the candidate in the optimization. In this paper, the new method is utilized to conduct an optimal scheme of the switching material of the RF-MEMS shunt capacitive switch, the sintering parameters of natural hydroxyapatite and the optimal design of the connecting claw jig.

Methods: All performance utility indicators of candidate materials are divided into two groups, i.e., beneficial or unbeneficial types for the selection process; each performance utility indicator contributes quantitatively to a partial preferable probability and the product of all partial preferable probabilities makes the total preferable probability of a candidate, which transfers a multi–objective optimization problem into a single–objective optimization one and represents a uniquely decisive index in the competitive selection process.

Results: Cu is the appropriate material in the material selection for RF - MEMS shunt capacitive switches; the optimal sintering parameters of natural hydroxyapatite are at 1100℃ and 0 compaction pressure; and the optimal scheme is scheme No 1 for the optimal design of a connecting claw jig.

Conclusion: The probability-based multi-objective optimization can be easily used to deal with an optimal problem objectively in material engineering.

Key words: multi-objective optimization, probability theory, preferable probability, material engineering, scheme selection.

Introduction

It has been more than 40 years (Ashby, 2000) since early works in material selection appeared; many methods have been proposed to analyze a big amount of data involved in the material selection process so as to obtain an appropriate result.

Various algorithms (techniques) have been developed, including Ashby's method (Ashby, 2000; Ashby et al, 2004), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Vlse Kriterijumska Optimizacija Kompromisno Resenje (VIKOR), Multi Attribute Decision Making (MADM), Analytical Hierarchy Process (AHP), Simple Additive Weighted (SAW) method and Multi–Objective Optimization on the basis of Ratio Analysis (MOORA), etc (Zheng et al, 2021). Ashby's method is difficult to be applied in cases which involve multiple criteria of selection (Ashby, 2000; Ashby et al, 2004; Zheng et al, 2021). Deshmukh et al employed the multi–objective optimization (MOO) techniques of TOPSIS and VIKOR to perform the material selection of the switching structure for RE-MEMS shunt capacitive switches (Deshmukh & Angira, 2019). However, there exist inherent problems of additive algorithms and subjective factors in the MADM, AHP, MOORA, TOPSIS and VIKOR due to their fatal scaling or normalization processes (Zheng et al, 2021).

Recently, a new probability-based multi-objective optimization method was developed (Zheng et al, 2021), attempting to solve the inherent problems of personal and subjective factors in the previous multi–objective optimization methods. The novel concept of preferable probability was introduced to reflect the preference degree of a candidate in the optimization where all performance utility indicators of candidates are divided into beneficial or unbeneficial types for the selection. Each performance utility indicator of a candidate contributes to a partial preferable probability quantitatively, and the total preferable probability of a candidate is the product of all partial preferable probabilities from the viewpoint of the probability theory, which is the overall and unique decisive index in the competitive selection process. The new multi-objective optimization method was also extended with the application of the multi-objective orthogonal test design method (OTDM) and the

uniform test design method (UTDM), which results in appropriate achievements (Zheng et al, 2021).

In this paper, the new probability-based multi–objective optimization method is used to perform the optimal scheme in material engineering, which includes the selection of switching material of the RF-MEMS shunt capacitive switch, the optimization of the sintering parameters of natural hydroxyapatite and the optimal design of a connecting claw jig.

Brief introduction to the new multi–objective optimization method

In the new probability-based multi–objective optimization method (Zheng et al, 2021), a beneficial utility index of material performance indicator contributes to a partial preferable probability in a positively linear manner, i.e.,

$$P_{ij} = \alpha_{ij} X_{ij},\ i = 1, 2,...,n;\ j = 1, 2,..m. \quad (1)$$

In Eq. (1), X_{ij} is the j^{th} beneficial utility index of the material performance indicator of the i^{th} candidate material; P_{ij} represents the partial preferable probability of the beneficial utility index X_{ij}; n is the total number of candidate materials in the material group involved; m is the total number of the utility indices of each candidate material in the group; α_j is the normalized factor of the j^{th} utility index of the material performance indicator, $\alpha_{ij} = 1/(n\overline{X}_j)$, and $\overline{X}_j$ is the arithmetic mean value of the utility index of the material performance indicator in the material group involved.

Equivalently, the unbeneficial utility index of the material performance indicator contributes to a partial preferable probability in a negatively linear manner, i.e.,

$$P_{ij} = \beta_{ij}(X_{jmax} + X_{jmin} - X_i),\ i = 1, 2,...,n;\ j = 1, 2,..m. \quad (2)$$

In Eq. (3), $X_{j\max}$ and $X_{j\min}$ represent the maximum and minimum values of the utility indices X_j of the material performance indicator in the material group, respectively, and β_j is the normalized factor of the j^{th} utility indices of the material performance indicator, $\beta_{ij} = 1/[n(X_{j\min} + X_{j\max}) - n\overline{X}_j]$.

Moreover, the total / comprehensive preferable probability of the i^{th} candidate material is the product of its partial preferable probability P_{ij} of each utility index of the material performance indicator in the overall

selection due to the “simultaneous optimization” of the multi-objects in the viewpoint of probability theory (Zheng et al, 2021), i.e.,

$$P_i = P_{i1} \cdot P_{i2} \cdots P_{im} = \prod_{j=1}^{m} P_{ij} \ . \tag{3}$$

The total preferable probability of a candidate is the uniquely decisive index in the overall selection process competitively, which transfers a multi–objective optimization problem (MOOP) into a single – objective optimization one. The main characteristic of the new probability-based multi–objective optimization is that the treatment for both beneficial utility index and unbeneficial utility index is equivalent and conformable, which is without any artificial or subjective scaling factors involved in the process.

Application of probability-based multi–objective optimization in material engineering

1) Multi–objective optimization in the material selection of RF-MEMS shunt capacitive switches

Radio Frequency Micro Electro Mechanical Systems (RF-MEMS) is a promising technology for implementing passive devices in future wireless communication systems (Deshmukh & Angira, 2019). Switches have drawn more attention due to their frequent use in many cases in wireless communication systems. An RF-MEMS technology-based switch has low insertion loss, high isolation, high linearity and less power consumption (Deshmukh & Angira, 2019). Its shunt capacitive switch has two stable states i.e., up-state and down-state (Deshmukh & Angira, 2019). Power can flow from the input port to the output port in the switch upstate, while it stands at the off-state in its down-state (Deshmukh & Angira, 2019; Angira & Rangra, 2015a; Angira & Rangra, 2015b).

The optimization of the performance of the switching structure involves many parameters (criteria), such as pull-in voltage, RF response (insertion loss and isolation), maximum displacement, thermal conductivity, etc (Deshmukh & Angira, 2019; Angira & Rangra, 2015a; Angira & Rangra, 2015b). Since many parameters are involved, it can be seen as a MOOP in the performance optimization of the switching material selection. Therefore, a MOOP can be used to decrease human effort since a large number of materials are available in practice, forming a material bank together with many manufacturing processes and selection attributes (Zheng et al, 2021).

Yang et al pointed out that if different normalization methods are applied, significant different results may be produced (Yang et al, 2021). Podviezko et al also stressed that different normalization of data applying to popular MCDM methods such as SAW or TOPSIS could lead to significant differences in the assessment (Podviezko & Podvezko, 2015). As a consequence, many researchers paid a lot of attention to the choice of the normalization type. However, it is still puzzling which normalization method is better and how to determine final results of material selection from different normalization algorithms.

A) Utility indices of the material performance indicators in the material selection of RF - MEMS shunt capacitive switches

In the study of Deshmukh & Angira (2019), the optimal objectives for this purpose are low pull–in voltage, low RF loss, high thermal conductivity and maximum displacement of the beam structure. As a result, the square root of Young's modulus of the material $E^{0.5}$, the electrical resistive coefficient ρ_e, the thermal conductivity of the material λ, the ratio of the fracture strength σ_f to Young's modulus E of the material, σ_f/E, are taken as the optimal utility indices of the material attribute indicators (Deshmukh & Angira, 2019).

B) Divisions of the utility indices in the material selection of RF - MEMS shunt capacitive switches

From analyzing the requirements of the optimizations of the bridge of RF-MEMS shunt capacitive switches, i.e., higher pull-in voltage (V_p), lower RF loss, higher thermal conductivity and the higher maximum displacement of the switch beam (Deshmukh & Angira, 2019), the utility indices of the square root of Young's modulus of the material, $E^{0.5}$, the thermal conductivity of the material, λ, the ratio of the fracture strength σ_f to Young's modulus E of the material, σ_f/E, belong to the beneficial type of the material performance index, while the electrical resistive coefficient, ρ_e, belongs to the unbeneficial type of the material performance index in the assessment.

C) Assessment results

The values of the conventional material performance indicators for various materials are given in Table 1 (Deshmukh & Angira, 2019).

The partial preferable probabilities of the utility indices of $E^{0.5}$, λ and ρ_e and σ_f/E and the total preferable probabilities are assessed according to Equations (1) through (5), respectively, shown in Table 2. In addition,

the ranking here by using the new probability-based multi–objective optimization method is given in Table 2 together with those of Vikor and Topsis from Ref. (Deshmukh & Angira, 2019) for comparison.

Table 1 – Conventional material performance indicators for various materials (Deshmukh & Angira, 2019)
Таблица 1 – Стандартные показатели эффективности материалов для различных материалов (Deshmukh & Angira, 2019)
Табела 1 – Индикатори уобичајених перформанси материјала за различите материјале (Deshmukh & Angira, 2019)

Mat.	Young's modulus E (GPa)	Electrical resistive coefficient ρ_e (Ω m) 10^{-8}	Thermal conductivity λ (W/m·K)	Fracture strength σ_f (MPa)	(σ_f/E) $\times 10^3$
Ni	193	6.99	90	345	1.7876
Au	70	2.44	315	220	3.1429
Al	70	2.82	204	47	0.6714
Ag	83	1.59	407	110	1.3253
Pt	168	10.5	73	125	0.7440
Cu	117	1.68	386	314	2.6838
Cr	279	12.9	90	370	1.3262
W	411	5.28	163	1725	4.1971
Co	209	6.24	69	675	3.2297
Fe	211	9.61	73	540	2.5592

Table 2 – Partial preferable probabilities and total preferable probabilities for various materials for shunt capacitive switch optimization
Таблица 2 – Частичные предпочтительные вероятности и общие предпочтительные вероятности для различных материалов при оптимизации емкостного шунтирующего переключателя
Табела 2 – Делимичне пожељне вероватноће и укупне пожељне вероватноће за различите материјале у оптимизацији капацитивног прекидача шанта

Mat.	$P_{E\wedge 0.5}$	$P_{\rho e}$	P_{λ}	$P_{\sigma f/E}$	$P_t \times 10^4$	Rank here	Rank Vikor	Rank Topsis
Ni	0.1073	0.0884	0.0481	0.0825	0.3766	6	6	6
Au	0.0646	0.1420	0.1684	0.1451	2.2423	3	1	1
Al	0.0646	0.1375	0.1091	0.0310	0.3005	7	4	4
Ag	0.0704	0.1520	0.2176	0.0612	1.4242	4	3	3
Pt	0.1001	0.0470	0.0390	0.0343	0.0631	10	8	9
Cu	0.0835	0.1510	0.2064	0.1239	3.2248	1	2	2
Cr	0.1290	0.0187	0.0481	0.0612	0.0712	9	10	10
W	0.1566	0.1085	0.0872	0.1937	2.8697	2	9	7
Co	0.1117	0.0972	0.0369	0.1490	0.5971	5	5	5
Fe	0.1122	0.0575	0.0390	0.1181	0.2975	8	7	8

It can be seen from Table 2 that the appropriate material from the new multi–objective optimization method is Cu, which is different from those of Vikor and Topsis from (Deshmukh & Angira, 2019); this is because of the inherent defects of personal and subjective factors in Vikor and Topsis (Deshmukh & Angira, 2019).

In fact, the evaluation result of the new probability-based method for multi–objective optimization in material selection is no need to equal to those of other previous approaches exactly due to their involvements of personal or other subjective coefficients.

2) Optimization of sintering parameters of natural hydroxyapatite

Abifarin conducted the optimization of hydroxyapatite (HAp) mechanical characteristics using Taguchi grey relational analysis design which includes hardness and compressive strength (Abifarin, 2021). Three levels of sintering temperature and two levels of compaction pressure are employed during sintering (Abifarin, 2021). The design and the results are shown in Table 3. Again, the probability-based multi-objective optimization is used to conduct the assessment with hardness and compressive strength as the beneficial type index. The evaluation results are shown in Table 4.

Table 3 – Design and the results of HAp
Таблица 3 – Разработка и результаты гидроксиапатита
Табела 3 – Пројектовање и резултати хидроксиапатита

No	Pressure	Temperature °C	Hardness	Compressive Strength
1	0	900	0.54	0.39
2	0	1000	0.838	0.58
3	0	1100	0.940	0.84
4	5	900	0.656	0.34
5	5	1000	0.929	0.5
6	5	1100	1.103	0.69

Table 4 – Evaluation results of HAp
Таблица 4 – Результаты оценки гидроксиапатита
Табела 4 – Резултати оцене хидроксиапатита

	Partial preferable probability		Total	
No	Hardness	Strength	$Pt*10^2$	Rank
1	0.1079	0.1168	1.2596	6
2	0.1674	0.1737	2.9069	3
3	0.1878	0.2515	4.7225	1
4	0.1311	0.1018	1.3340	5
5	0.1856	0.1497	2.7781	4
6	0.2203	0.2066	4.5518	2

Table 4 indicates that the optimal sintering parameters of natural hydroxyapatite are at 1100°C and 0 compaction pressure.

3) Optimal design of a connecting claw jig

Yan et al conducted the multi-objective optimal design of a connecting claw jig with ANSYS Workbench finite element analysis software (Yan et al, 2021). The maximum equivalent stress (MPa) Y_1, the weight (kg) Y_2, the minimum safety factor Y_3 and the maximum deformation (mm) Y_4 of the claw jig are taken as the optimization objectives, while the thickness of the substrate FD_1 (mm) x_1, the angle of the connecting claw A1 (°) x_2, the thickness of the connecting claw FD_2 (mm) x_3, and the outside diameter of the jig base R_1 (mm) x_4 are taken as the input variables.

After the simulation and the analysis, three candidate schemes with good objective functions are selected by the system, as shown in Table 5. The object Y_3 is a beneficial type index, while Y_1, Y_2 and Y_4 are all unbeneficial type indexes. The evaluation results are shown in Table 6.

Table 6 shows that the optimal scheme is scheme No 1.

Table 5 – Three candidate schemes of the connecting claw jig
Таблица 5 – Три возможные схемы кулачковой муфты
Табела 5 – Шеме три кандидата за канџасту спојницу

Original scheme	x_1 (mm)	x_2 (°)	x_3 (mm)	x_4 (mm)	Y_1 (MPa)	Y_2 (kg)	Y_3	Y_4 (mm)
	56	79	38	32.5	151.22	6.176	1.6532	1.171
1	54.125	73.13	35.414	31.051	128.42	5.615	1.9467	0.923
2	48.125	73.77	37.982	32.395	143.31	5.577	1.7444	1.043
3	46.625	76.38	39.908	30.715	161.48	5.620	1.5482	1.375

Table 6 – Evaluation results of the connecting claw jig
Таблица 6 – Результаты оценки кулачковой муфты
Табела 6 – Резултати оцена канџасте спојнице

No.	Partial preferable probability				Total	
	Y_1	Y_2	Y_3	Y_4	Pt*100	Rank
1	0.3700	0.3327	0.3716	0.3870	1.7697	1
2	0.3358	0.3349	0.3329	0.3532	1.3229	2
3	0.2942	0.3324	0.2955	0.2598	0.7507	3

Conclusion

The application of the new probability-based multi–objective optimization method in dealing with three optimal problems of material engineering has shown that: the appropriate material (Cu) is successfully selected, which meets the requirements of the optimizations of the bridge of RF - MEMS shunt capacitive switches; the optimal sintering parameters of natural hydroxyapatite are at 1100°C and 0 compaction pressure; and the optimal scheme of the connecting claw jig is scheme No 1. The main feature of the new probability-based multi–objective optimization method is that the treatment is equivalent and conformable for both the beneficial utility index and the unbeneficial utility index, without any artificial or subjective scaling factors involved in the process.

References

Abifarin, J.K. 2021 Taguchi grey relational analysis on the mechanical properties of natural hydroxyapatite: effect of sintering parameters. *The International Journal of Advanced Manufacturing Technology*, 117, pp.49-57. Available at: https://doi.org/10.1007/s00170-021-07288-9.

Angira, M. & Rangra, K. 2015a. Design and investigation of a low insertion loss, broadband, enhanced self and hold down power RF-MEMS switch. *Microsystem Technologies*, 21(6), pp.1173-1178. Available at: https://doi.org/10.1007/s00542-014-2188-6.

Angira, M. & Rangra, K. 2015b. Performance improvement of RF-MEMS capacitive switch via asymmetric structure design. *Microsystem Technologies*, 21(7), pp.1447-1452. Available at: https://doi.org/10.1007/s00542-014-2222-8.

Ashby, M.F. 2000. Multi-Objective optimization in material design and selection. *Acta Materialia*, 48(1), pp.359-369. Available at: https://doi.org/10.1016/S1359-6454(99)00304-3.

Ashby, M.F., Bréchet, Y.J.M., Cebon, D. & Salvo, L. 2004. Selection strategies for materials and processes. *Materials & Design*, 25(1), pp.51-67. Available at: https://doi.org/10.1016/S0261-3069(03)00159-6.

Deshmukh, D. & Angira, M. 2019. Investigation on Switching Structure Material Selection for RF-MEMS Shunt Capacitive Switches Using Ashby, TOPSIS and VIKOR. *Transactions on Electrical and Electronic Materials*, 20, pp.181-188. Available at: https://doi.org/10.1007/s42341-018-00094-3.

Podviezko, A. & Podvezko, V. 2015. Influence of data transformation on multicriteria evaluation result. *Procedia Engineering*, 122, pp.151-157. Available at: https://doi.org/10.1016/j.proeng.2015.10.019.

Yan, Y., Fu, N., Zhang, X., Wang, C., Sun, J. & Lu, L. 2021. Research on the Multi-Objective Optimization Design of Connecting Claw Jig. *International Journal of Steel Structures*, 21(6), pp.1911-1920. Available at: https://doi.org/10.1007/s13296-021-00542-6.

Yang, W-C., Chon, S-K., Choe, C-M. & Yang, J-Y. 2021. Materials selection method using TOPSIS with some popular normalization methods. *Engineering Research Express*, 3(1), art.number: 015020. Available at: https://doi.org/10.1088/2631-8695/abd5a7.

Zheng, M., Wang, Y. & Teng, H. 2021. A New "Intersection" Method for Multi-Objective Optimization in Material Selection. *Tehnički glasnik*, 15(4), pp.562-568. Available at: https://doi.org/10.31803/tg-20210901142449.

ПРИМЕНЕНИЕ МНОГОЦЕЛЕВОЙ ОПТИМИЗАЦИИ, ОСНОВАННОЙ НА ВЕРОЯТНОСТИ В МАТЕРИАЛОВЕДЕНИИ

Маошенг Чжэн
Северо-западный политехнический университет,
факультет химической инженерии,
г. Сиань, Народная Республика Китай

РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА:
27.47.00 Математическая кибернетика;
27.47.19 Исследование операций,
45.00.00 ЭЛЕКТРОТЕХНИКА:
45.09.00 Электротехнические материалы
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Несмотря на то, что существует множество методов решения проблемы выбора материала на основе аддитивных алгоритмов, такие алгоритмы по своей сути содержат недостатки и субъективные факторы. С целью преодоления недостатков этих методов, недавно была разработана многокритериальная вероятностная оптимизация, которая вводит новую концепцию предпочтительной вероятности, показывающую степень предпочтительности кандидата в процессе оптимизации. В данной статье используется новый метод в разработке оптимальной схемы материала для емкостного шунтирующего переключателя в радиочастотных микроэлектромеханических системах (РЧ МЭМС), параметрах спекания природного гидроксиапатита, а также для оптимальной разработки кулачковой муфты.

Методы: Все показатели полезности материалов–кандидатов делятся на две группы, полезные или невыгодные для процесса отбора; каждый показатель полезности вносит количественный вклад в частичную предпочтительную вероятность, а произведение всех частичных предпочтительных вероятностей составляет общую

предпочтительную вероятность кандидата, что переводит проблему многокритериальной оптимизации в проблему оптимизации с одним критерием и представляет собой уникальный индекс в процессе конкурсного отбора.

Результаты: Медь оказалась подходящим материалом при выборе материалов для емкостных шунтирующих переключателей в радиочастотных микроэлектромеханических системах (РЧ МЭМС); оптимальные параметры спекания природного гидроксиапатита − 1100° C при нулевом давлении сжатия, а оптимальной схемой проектирования кулачковой муфты является схема №1.

Выводы: Многокритериальная оптимизация на основе вероятностей может широко применяться при принятии объективных решений оптимальных проблем в матереаловедении.

Ключевые слова: многокритериальная оптимизация, теория вероятностей, предпочтительная вероятность, материаловедение, выбор схемы.

ПРИМЕНА ВИШЕКРИТЕРИЈУМСКЕ ОПТИМИЗАЦИЈЕ ЗАСНОВАНА НА ВЕРОВАТНОЋИ У ТЕХНОЛОГИЈИ МАТЕРИЈАЛА

Маошенг Џенг
Универзитет Северозапад, Факултет хемијског инжењерства,
Сијан, Народна Република Кина

ОБЛАСТ: математика, материјали
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Иако постоји много метода за решавање проблема селекције материјала заснованих на адитивним алгоритмима, такви алгоритми инхерентно садрже недостатке и субјективне факторе. Ради превазилажења слабости поменутих метода, недавно је развијена вишекритеријумска оптимизација заснована на вероватноћи која уводи нови концепт пожељне вероватноће који показује степен пожељности кандидата при оптимизацији. У овом раду користи се нов метод за извођење оптималне шеме за материјал за капацитивну склопку шанта у радиофреквенцијским микроелектромеханичким системима (РФ МЕМС), за параметре синтеровања природног хидроксиапатита, као и за оптимално пројектовање канџасте спојнице.

Zheng, M., Application of probability-based multi–objective optimization in material engineering, pp.1-12

Методе: Сви показатељи перформанси корисности материјала – кандидата деле се на корисне и некорисне за селекцију. Сваки показатељ перформанси корисности квантитативно доприноси делимичној пожељној вероватноћи, док производ свих делимичних пожељних вероватноћа чини укупну пожељну вероватноћу кандидата, чиме се проблем вишекритеријумске оптимизације преводи у проблем једнокритеријумске оптимизације и представља јединствени одлучујући индекс у компетитивном процесу селекције.

Резултати: Бакар се показао као одговарајући материјал при селекцији материјала за капацитивне склопке шанта у радиофреквенцијским микроелектромеханичким системима (РФ МЕМС). Оптимални параметри синтеровања природног хидроксиапатита су 1100℃ и нулти притисак сабијања, а оптимална шема за пројектовање канџасте спојнице јесте шема број 1.

Закључак: Вишекритеријумска оптимизација на бази вероватноће може се једноставно применити за објективно решавање оптималног проблема у технологији материјала.

Кључне речи: вишекритеријумска оптимизација, теорија вероватноће, пожељна вероватноћа, технологија материјала, селекција шеме.

Paper received on / Дата получения работы / Датум пријема чланка: 12.12.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 29.12.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 31.12.2021.

ESTIMATING VERTEX-DEGREE-BASED ENERGIES

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/vojtehg70-35584;https://doi.org/10.5937/vojtehg70-35584

FIELD: Mathematics
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: In the current literature, several dozens of vertex-degree-based (VDB) graph invariants are being studied. To each such invariant, a matrix can be associated. The VDB energy is the energy (= sum of the absolute values of the eigenvalues) of the respective VDB matrix. The paper examines some general properties of the VDB energy of bipartite graphs.

Results: Estimates (lower and upper bounds) are established for the VDB energy of bipartite graphs in which there are no cycles of size divisible by 4, in terms of ordinary graph energy.

Conclusion: The results of the paper contribute to the spectral theory of VDB matrices, especially to the general theory of VDB energy.

Keywords: vertex-degree-based graph invariant, vertex-degree-based matrix, vertex-degree-based energy, energy (of graph).

Introduction

Let G be a simple graph with the vertex set $\mathbf{V}(G)$ and the edge set $\mathbf{E}(G)$.

If the vertices $u, v \in \mathbf{V}(G)$ are adjacent, then the edge connecting them is denoted by uv. The number of edges incident to a vertex v is the degree of that vertex, and is denoted by $d(v)$. The minimum and maximum vertex degrees are denoted by δ and Δ, respectively.

Let $\mathbf{V}(G) = \{v_1, v_2, \ldots, v_n\}$. Then the adjacency matrix $\mathbf{A}(G) = [a_{ij}]$ of the graph G is the symmetric matrix of order n, whose elements are (Cvetković et al, 2010):

$$a_{ij} = \begin{cases} 1 & \text{if } v_i v_j \in \mathbf{E}(G) \\ 0 & \text{if } v_i v_j \notin \mathbf{E}(G) \\ 0 & \text{if } i = j\,. \end{cases} \tag{1}$$

If the eigenvalues of $\mathbf{A}(G)$ are $\lambda_1, \lambda_2, \ldots, \lambda_n$, then the (ordinary) *energy* of the graph G is defined as

$$\mathcal{E} = \mathcal{E}(G) = \sum_{i=1}^{n} |\lambda_i|\,. \tag{2}$$

The theory of graph energy is nowadays elaborated in due detail (Li et al, 2012; Ramane, 2020).

In the chemical and mathematical literature, a variety of vertex-degree-based (VDB) graph invariants of the form

$$\mathcal{I} = \mathcal{I}(G) = \sum_{uv \in \mathbf{E}(G)} f\big(d(u), d(v)\big) \tag{3}$$

has been considered, where f is a suitably chosen function, with a property $f(x, y) = f(y, x)$ (Kulli, 2020; Todeschini & Consonni, 2009).

These are usually referred to as *topological indices*. Of these, we list here a few most popular and best studied ones:

$f(x,y)$	name of index	type
$x+y$	first Zagreb	$\uparrow$
$x\,y$	second Zagreb	$\uparrow$
x^2+y^2	forgotten	$\uparrow$
$\sqrt{x^2+y^2}$	Sombor	$\uparrow$
$\sqrt{x+y}$	nirmala	$\uparrow$
$1/\sqrt{x\,y}$	Randić	$\downarrow$
$1/\sqrt{x+y}$	sum-connectivity	$\downarrow$
$2/(x+y)$	harmonic	$\downarrow$
$1/x^2+1/y^2$	inverse degree	$\downarrow$
$1/\sqrt{x^2+y^2}$	modified Sombor	$\downarrow$
$[(x+y-2)/(xy)]^{1/2}$	atom-bond-connectivity	$\sim$
$\lvert x-y\rvert$	Albertson	$\sim$

The parameters x and y (being vertex degrees) always satisfy the condition $x \geq 1$, $y \geq 1$. Bearing this in mind, we immediately recognize that most VDB indices are either monotonically increasing ($\uparrow$) or monotonically decreasing functions ($\downarrow$) of the vertex degrees. Only a few such indices do not possess such a monotonicity property ($\sim$).

It should be noted that for practically all VDB indices of type $\uparrow$ that exist in the literature, the condition $f(x,y) \geq 1$ is satisfied for all values of x and y that occur for the edges of graphs. Analogously, for practically all VDB indices of type $\downarrow$, $0 < f(x,y) \leq 1$ holds for all values of x and y.

Taking into account Eqs. (1) and (3), we introduce the VDB matrix $\mathbf{A}_{\mathcal{I}}(G) = \big[(a_{\mathcal{I}})_{ij}\big]$ via

$$(a_{\mathcal{I}})_{ij} = \begin{cases} f\big(d(v_i), d(v_)\big) & \text{if } v_i v_j \in \mathbf{E}(G) \\ 0 & \text{if } v_i v_j \notin \mathbf{E}(G) \\ 0 & \text{if } i = j\,. \end{cases} \tag{4}$$

If its eigenvalues are $\mu_1, \mu_2, \ldots, \mu_n$, then the energy pertaining to the VDB invariant $\mathcal{I}$, Eq. (3), is

$$\mathcal{E}_{\mathcal{I}} = \mathcal{E}_{\mathcal{I}}(G) = \sum_{i=1}^{n} |\mu_i| \,. \tag{5}$$

For recent works on the investigation of this class of graph-spectral invariants see (Das et al, 2018; Gutman, 2020, 2021; Gutman et al, 2022, 2021; Li & Wang, 2021; Shao et al, 2021).

Main results

A cycle of length p is a cycle consisting of (exactly) p vertices $v_1, v_2, \ldots, v_p$, so that v_i and v_{i+1} are adjacent for $i = 1, 2, \ldots, p-1$, and also v_1 and v_p are adjacent. As it is well known, a graph G is bipartite if and only if all its cycles (if any) are of even length. In this paper, we prove the results valid for bipartite graphs which do not possess cycles of a length divisible by 4. Let G be such a graph. Without loss of generality, we assume that G is connected.

Let the graph energy $\mathcal{E}$ and the VDB energy $\mathcal{E}_{\mathcal{I}}$ be the quantities defined via Eqs. (2) and (5), and let f be the function specified in Eq. (3). Let δ ad Δ be the smallest and largest vertex degrees of G.

THEOREM 1. *Let G be a bipartite graph with no cycle of size divisible by 4. Then*

$$f(\delta, \delta)\, \mathcal{E}(G) \leq \mathcal{E}_{\mathcal{I}}(G) \leq f(\Delta, \Delta)\, \mathcal{E}(G)$$

holds for all VDB invariants in which the function f is monotonically increasing and $f(x, y) \geq 1$ for all vertex degrees x and y. Equality on both sides holds if and only if G is a regular graph, in which case $\delta = \Delta$.

The examples of the VDB invariants for Theorem 1 are the above listed first and second Zagreb, forgotten, Sombor, and nirmala indices.

THEOREM 2. *Let G be a bipartite graph with no cycle of size divisible by 4. Then*

$$f(\Delta, \Delta)\, \mathcal{E}(G) \leq \mathcal{E}_{\mathcal{I}}(G) \leq f(\delta, \delta)\, \mathcal{E}(G)$$

holds for all VDB invariants in which the function f is monotonically decreasing and $0 < f(x, y) \leq 1$ for all vertex degrees x and y. Equality on both sides holds if and only if G is a regular graph.

The examples of the VDB invariants for Theorem 2 are the above listed Randić, sum-connectivity, harmonic, and modified Sombor indices, as well as the inverse degree.

A tree is a connected graph with no cycles. Therefore, Theorems 1 and 2 apply to trees. For any tree $\delta = 1$, but Theorems 1 and 2 can be slightly strengthened.

THEOREM 3. *Let T be a tree with $n \geq 3$ vertices. Then*

$$f(1,2)\,\mathcal{E}(T) \leq \mathcal{E}_{\mathcal{I}}(T) < f(\Delta,\Delta)\,\mathcal{E}(T)$$

holds for all VDB invariants in which the function f is monotonically increasing and $f(x,y) \geq 1$ for all x, y. Equality on the left-hand side holds if and only if $n = 3$.

THEOREM 4. *Let T be a tree with $n \geq 3$ vertices. Then*

$$f(\Delta,\Delta)\,\mathcal{E}(T) < \mathcal{E}_{\mathcal{I}}(T) \leq f(1,2)\,\mathcal{E}(T)$$

holds for all VDB invariants in which the function f is monotonically decreasing and $0 < f(x,y) \leq 1$ for all x, y. Equality on the right-hand side holds if and only if $n = 3$.

In addition to trees, Theorems 1 and 2 are applicable to various classes of cycle-containing graphs. Of these, of particular interest may be the hexagonal systems (molecular graphs of benzenoid hydrocarbons) (Gutman & Cyvin, 1989). All their vertices are of degrees 2 and 3. The so-called catacondesned hexagonal systems (= hexagonal systems having no internal vertices) are known to possess only cycles of size $4p + 2$. For these molecular graphs

$$f(2,2)\,\mathcal{E}(G) < \mathcal{E}_{\mathcal{I}}(G) < f(3,3)\,\mathcal{E}(G)\,. \tag{6}$$

or

$$f(3,3)\,\mathcal{E}(G) < \mathcal{E}_{\mathcal{I}}(G) < f(2,2)\,\mathcal{E}(G)\,. \tag{7}$$

depending on whether $f(x,y)$ monotonically increases or decreases.

Hexagonal systems possessing internal vertices have cycles of size $4p$, $p = 3, 4, \ldots$, and thus Theorems 1 and 2 are not applicable. We nevertheless conjecture that estimates (6) and (7) are valid for all hexagonal systems.

In order to prove the above theorems, we need an auxiliary result, stated below as Lemma 3.

Energy of a weighted bipartite graph

The main part of the results outlined in this section was reported in (Gutman et al, 2021). These are repeated here (in an abbreviated form) in order to maintain completeness. Also, a few errors committed in (Gutman et al, 2021) are corrected.

Let G be a bipartite graph with n vertices. Let G_w be obtained from G by associating weighs to its edges, so that w_{ij} is the weight of the edge ij. Then the characteristic polynomial of G_w is of the form (Cvetković et al, 2010)

$$\phi(G_w, \lambda) = \lambda^n + \sum_{k \geq 1} (-1)^k \, c(G_w, k) \, \lambda^{n-2k} \tag{8}$$

whereas the energy of G_w satisfies the equality (Gutman, 1977, 2020; Li et al, 2012)

$$\mathcal{E}(G_w) = \frac{2}{\pi} \int_0^{+\infty} \frac{dx}{x^2} \, \ln \left[1 + \sum_{k \geq 1} c(G_w, k) \, x^{2k} \right]. \tag{9}$$

Note that $\mathcal{E}(G_w)$ is a monotonically increasing function of any of the coefficients $c(G_w, k)$.

According to the Sachs theorem (Cvetković et al, 2010)

$$(-1)^k \, c(G_w, k) = \sum_{\sigma \in \mathcal{S}_{2k}(G_w)} (-1)^{p(\sigma)} \, 2^{c(\sigma)} \, w(\sigma) \tag{10}$$

where $\mathcal{S}_k(G_w)$ is the set of all Sachs graphs of G_w possessing exactly $2k$ vertices, and where σ is an element of $\mathcal{S}_{2k}(G_w)$, containing $p(\sigma)$ components, of which $c(\sigma)$ are cycles. The weight of the Sachs graph σ is equal to the product of the weights of its components. If the isolated edge ij is a component of σ, then its weight is w_{ij}^2. If a cycle Z is a component of σ, then its weight is the product of weights of the edges contained in Z.

LEMMA 1. (Gutman et al, 2021) *If the Sachs graph $\sigma \in \mathcal{S}_{2k}(G_w) \neq \emptyset$ does not contain cycles whose size is divisible by 4, then*

$$(-1)^k \, (-1)^{p(\sigma)} \, 2^{c(\sigma)} > 0 \, .$$

Proof. The Sachs graph σ has $p(\sigma)$ components. Let among them be $r_0 \geq 0$ isolated edges, whose total number of vertices is $2r_0$. Let σ contain $r_1 \geq 0$ cycles, whose total number of vertices is $4x+2\,r_1$ for some integer x. Thus, $2k = 2r_0 + 4x + 2\,r_1$.

Case 1: $2k$ is not divisible by 4. Then $(-1)^k = -1$ whereas $r_0+r_1 = p(\sigma)$ is odd. Therefore, $(-1)^k\,(-1)^{p(\sigma)} > 0$ and the claim of Lemma 1 holds.

Case 2: $2k$ is divisible by 4. Then $(-1)^k = +1$ whereas $r_0 + r_1 = p(\sigma)$ is even, implying, again, $(-1)^k\,(-1)^{p(\sigma)} > 0$. □

Lemma 1 has the following noteworthy consequences:

LEMMA 2.
(a) Let G_w be an edge-weighted bipartite graph whose all cycles (if any) have size not divisible by 4, and let the weights of all its edges be positive-valued. Then for any Sachs graph $\sigma \in \mathcal{S}_{2k}(G_w) \neq \emptyset$,

$$(-1)^k\,(-1)^{p(\sigma)}\,2^{c(\sigma)}\,w(\sigma) > 0\,.$$

(b) Therefore, because of Eq. (10), the coefficients $c(G_w, k)$ in Eq. (8) are non-negative and are the monotonically increasing functions of the edge-weights.
(c) Therefore, because of Eq. (9), the energy of the graphs G_w is a monotonically increasing function of the edge-weights.

From Lemma 2(c), we obtain the result needed for our proofs:

LEMMA 3. *Let G_w be an edge-weighted bipartite graph whose all cycles (if any) have size not divisible by 4.*
(a) If for all edges $ij \in \mathbf{E}(G_w)$, the condition $w_{ij} \geq 1$ holds, then $\mathcal{E}(G_w) \geq \mathcal{E}(G)$. If $w_{ij} > 1$ for at least one edge ij, then $\mathcal{E}(G_w) > \mathcal{E}(G)$.
(b) If for all edges $ij \in \mathbf{E}(G_w)$, the condition $w_{ij} \leq 1$ holds, then $\mathcal{E}(G_w) \leq \mathcal{E}(G)$. If $w_{ij} < 1$ for at least one edge ij, then $\mathcal{E}(G_w) < \mathcal{E}(G)$.
(c) If in both cases (a) and (b), $w_{ij} = w$ holds for all edges $ij \in \mathbf{E}(G_w)$, then $\mathcal{E}(G_w) = w\,\mathcal{E}(G)$.

Proof of Theorems 1-4

The adjacency matrix $\mathbf{A}_{\mathcal{I}}(G)$, Eq. (4), could be viewed as the ordinary adjacency matrix of an edge-weighted modification of the graph G. Therefore, if the condition $f(d_{v_i}, d_{v_j}) > 1$ holds, and if $f(x, y)$ is an increasing

function for $x \geq 1$ and $y \geq 1$, then the lower bound of Theorem 1 follows by Lemma 3 if all $f(x, y)$ are replaced by $f(\delta, \delta)$. The upper bound is obtained if all $f(x, y)$ are replaced by $f(\Delta, \Delta)$.

The proof of Theorem 2 is analogous.

Theorems 3 and 4 are based on the fact that no tree with $n \geq 3$ vertices is a regular graph. The only tree having two adjacent degree-one vertices is the two-vertex tree. Therefore, for trees with 3 or more vertices, the minimal (resp. maximal) value of $f(x, y)$ is $f(1, 2)$.

References

Cvetković, D., Rowlinson, P. & Simić, K. 2010. *An Introduction to the Theory of Graph Spectra*. Cambridge: Cambridge University Press. ISBN: 9780521134088.

Das, K.C., Gutman, I., Milovanović, I., Milovanović, E. & Furtula, B. 2018. Degree-based energies of graphs. *Linear Algebra and its Applications*, 554, pp.185-204. Available at: https://doi.org/10.1016/j.laa.2018.05.027.

Gutman, I. 1977. Acyclic systems with extremal Hückel π-electron energy. *Theoretica chimica acta*, 45, pp.79-87. Available at: https://doi.org/10.1007/BF00552542.

Gutman, I. 2020. Relating graph energy with vertex-degree-based energies. *Vojnotehnički glasnik/Military Technical Courier*, 68(4), pp.715-725. Available at: https://doi.org/10.5937/vojtehg68-28083.

Gutman, I. 2021. Comparing degree-based energies of trees. *Contributions to Mathematics*, 4, pp.1-5. Available at: https://doi.org/10.47443/cm.2021.0030.

Gutman, I. & Cyvin, S.J. 1989. *Introduction to the theory of benzenoid hydrocarbons*. Berlin: Springer. Available at: https://doi.org/10.5860/choice.27-4521.

Gutman, I., Monsalve, J. & Rada, J. 2022. A relation between a vertex-degree-based topological index and its energy. *Linear Algebra and its Applications*, 636(March), pp.134-142. Available at: https://doi.org/10.1016/j.laa.2021.11.021.

Gutman, I., Redžepović, I. & Rada, J. 2021. Relating energy and Sombor energy. *Contributions to Mathematics*, 4, pp.41-44. Available at: https://doi.org/10.47443/cm.2021.0054.

Kulli, V.R. 2020. Graph indices. In: Pal, M., Samanta, S. & Pal, A. (Eds.), *Handbook of Research of Advanced Applications of Graph Theory in Modern Society*, pp.66-91. Hershey, USA: IGI Global. Available at: https://doi.org/10.4018/978-1-5225-9380-5.ch003.

Li, X., Shi, Y. & Gutman, I. 2012. Introduction. In: *Graph Energy*, pp.1-9. New York, NY: Springer. Available at: https://doi.org/10.1007/978-1-4614-4220-2_1.

Li, X. & Wang, Z. 2021. Trees with extremal spectral radius of weighted adjacency matrices among trees weighted by degree-based indices. *Linear Algebra and Its Applications*, 620, pp.61-75. Available at: https://doi.org/10.1016/j.laa.2021.02.023.

Ramane, H.S. 2020. Energy of graphs. In: Pal, M., Samanta, S., & Pal, A. (Eds.) *Handbook of Research on Advanced Applications of Graph Theory in Modern Society*, pp.267-296. Hershey, PA, USA: IGI Global. Available at: https://doi.org/10.4018/978-1-5225-9380-5.ch011.

Shao, Y., Gao, Y., Gao, W. & Zhao, X. 2021. Degree-based energies of trees. *Linear Algebra and Its Applications*, 621, pp.18-28. Available at: https://doi.org/10.1016/j.laa.2021.03.009.

Todeschini, R. & Consonni, V. 2009. *Molecular Descriptors for Chemoinformatics*. Weinheim: Wiley-VCH. ISBN: 978-3-527-31852-0.

ОЦЕНКА ЭНЕРГИЙ, ОНСОВАННЫХ НА СТЕПЕНИ ВЕРШИН

Иван Гутман

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

РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА:
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: В новейшей литературе изучаются десятки инвариантов графов, основанных на степени вершин (VDB). К каждому такому инварианту может присоединиться матрица. Энергия VDB - это энергия (= сумма абсолютных значений собственных значений) соответствующей матрицы VDB. В данной статье исследуются некоторые общие свойства VDB-энергии двудольных графов.

Результаты: Получены оценки (нижней и верхней границы) по энергии VDB двудольных графов, не имеющих циклов величины, кратной 4, в зависимости от обычной энергии графа.

Выводы: Результаты статьи вносят вклад в спектральную теорию матриц VDB, а особенно в общую теорию энергии VDB.

Ключевые слова: инвариант графа основанный на степени вершины, матрица основанная на степени вершины, энергия основанная на степени вершины, энергия (графа).

ПРОЦЕНА ЕНЕРГИЈА ЗАСНОВАНИХ НА СТЕПЕНИМА ЧВОРОВА

Иван Гутман

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

ОБЛАСТ: математика
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У новијој литератури проучавају се бројне графовске инваријанте засноване на степенима чворова (VDB). Свакој од ових инваријанти може се придружити матрица. VDB енергија је енергија (= збир апсолутних вредности сопствених вредности) одговарајуће VDB матрице. Рад истражује неке опште особине VDB енергије бипартитних графова.

Резултати: Добијене су процене (доње и горње границе) за VDB енергију бипартитних графова који немају циколве величине дељиве са 4, а у зависности од обичне графовске енергије.

Закључак: Резултати овог рада доприносе спектралној теорији VDM матрица, а посебно општој теорији VDB енергије.

Кључне речи: инваријанта заснована на степенима чворова, матрица заснована на степенима чворова, енергија заснована на степенима чворова, енергија (графа).

Paper received on / Дата получения работы / Датум пријема чланка: 27.12.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 04.01.2022.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 05.01.2022.

A DIFFERENT APPROACH TO $b_{(\alpha_n,\beta_n)}$-HYPERMETRIC SPACES

Akbar Dehghan Nezhad[a], *Nikola* Mirkov[b], *Vesna* Todorčević[c], *Stojan* Radenović[d]

[a] Iran University of Science and Technology, School of Mathematics, Narmak, Tehran, Islamic Republic of Iran, e-mail: dehghannezhad@iust.ac.ir, ORCID iD: https://orcid.org/0000-0003-4200-6892

[b] University of Belgrade, VINČA Institute of Nuclear Sciences - Institute of National Importance for the Republic of Serbia, Belgrade, Republic of Serbia, e-mail: nmirkov@vin.bg.ac.rs, **corresponding author**, ORCID iD: https://orcid.org/0000-0002-3057-9784

[c] University of Belgrade, Faculty of Organizational Sciences, Belgrade, Republic of Serbia, e-mail: vesna.todorcevic@fon.bg.ac.rs, ORCID iD: https://orcid.org/0000-0001-6206-3961

[d] University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Republic of Serbia, e-mail: radens@beotel.rs, ORCID iD: https://orcid.org/0000-0001-8254-6688

DOI: 10.5937/vojtehg70-35303;https://doi.org/10.5937/vojtehg70-35303

FIELD: Mathematics

ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: The aim of this paper is to present the concept of $b_{(\alpha_n,\beta_n)}$*-hypermetric spaces.*
Methods: Conventional theoretical methods of functional analysis.
Results: This study presents the initial results on the topic of $b_{(\alpha_n,\beta_n)}$*-hypermetric spaces. In the first part, we generalize an* n*-dimensional* $(n \geq 2)$ *hypermetric distance over an arbitrary non-empty set* X*. The* $b_{(\alpha_n,\beta_n)}$*-hyperdistance function is defined in any way we like, the only constraint being the simultaneous satisfaction of the three properties, viz, non-negativity and positive-definiteness, symmetry and* (α_n, β_n)*-triangle inequality. In the second part, we discuss the concept of* (α_n, β_n)*-completeness, with respect to this* $b_{(\alpha_n,\beta_n)}$*-hypermetric, and the fixed point theorem which plays an important role in applied mathematics in a variety of fields.*
Conclusion: With proper generalisations, it is possible to formulate

well-known results of classical metric spaces to the case of $b_{(\alpha_n,\beta_n)}$-hypermetric spaces.

Key words: $b_{(\alpha_n,\beta_n)}$-hypermetric spaces, G-metric, fixed point.

Introduction

In human effort to describe the surrounding world, the concept of distance has long been fundamental. Our intuitive understanding of distance as an exact value may however differ from its mathematical definition and its properties. If one is to include the measurement error, encountered in real life attempt to measure the distance between two objects, the distance will be defined as an interval. This is, for example, where we may come across a set-valued distance function. This approach will in fact be our main motivation for presenting a generalized concept of the distance as a set-valued function in this paper.

The notion of 2-metric spaces, as a possible generalization of metric spaces, was introduced by Gähler (Gähler, 1963). The 2-metric $d(x, y, z)$ is a function of three variables, and Gähler geometrically interpreted it as an area of triangle with vertices at x , y and z respectively.

B. C. Dhage, in his PhD thesis (1992), introduced the notion of D-metric (Dhage et al, 2000) spaces that generalize metric spaces. However, most of the claims concerning the fundamental topological properties of D-metric spaces are incorrect, as shown in 2003 by Mustafa and Sims (Mustafa & Sims, 2003). This led them to introduce the notion of G-metric spaces (Mustafa & Sims, 2006), as a generalization of the metric spaces. In this type of spaces, a non-negative real number is assigned to every triplet of elements.

The G-metric spaces were generalized to universal metrics by Dehghan Nezhad et al, in a series of papers (Dehghan Nezhad & Aral, 2011; Dehghan Nezhad & Khajuee, 2013; Dehghan Nezhad et al, 2017; Dehghan Nezhad et al, 2021; Dehghan Nezhad & Mazaheri, 2010). The interpretation of the perimeter of a triangle is applied, but this time on G-metric spaces. Since then, many authors have obtained fixed point results for G-metric spaces.

In an attempt to generalize the notion of a G-metric space to more than three variables, Khan first introduced the notion of a K-metric, and later the notion of a generalized n-metric space(for any $n \geq 2$) (Khan, 2012, 2014), in 1975. He also proved the common fixed point theorem for such spaces.

Bakhtin (Bakhtin, 1989) and Czerwik (Czerwik, 1993) generalized the structure of metric space by weakening the triangle inequality and called it the b-metric space. In 2017, Kamran et al. (Kamran et al, 2017) introduced the concept of extended b-metric space by further weakening the triangle inequality. For more details also see (Agarwal et al, 2015; Debnath et al, 2021; Kirk & Shahzad, 2014; Todorčević, 2019). Also, for a broader perspective on extended b-metric spaces, dislocated b-metric spaces, rectangular b-metric spaces, b-metric like spaces, and applications see (Younis et al, 2021a,b,c; Younis & Singh, 2021).

The main purpose of this paper is a generalization of universal metric spaces into $b_{(\alpha_n,\beta_n)}$-hypermetric spaces of the n-dimension.

REMARK 1. An ordered ring is a (usually commutative) ring R with a total order $\preceq$ such that for all a, b, and c in R:
i) if $a \preceq b$, then $a + c \preceq b + c$
ii) if $0 \preceq a$ and $0 \preceq b$, then $0 \preceq a \cdot b$.
We denote R^+ a set of non-negative elements of R, namely $R^+ := \{g \in R : 0 \preceq g\}$.

The concept of a b-metric space is initiated by Bakhtin (Bakhtin, 1989) and later used by Czerwick (Czerwik, 1993).

DEFINITION 1. *(Czerwik, 1993) Let X be a non-empty set and $d_b : X \times X \longrightarrow [0, +\infty)$ be a function satisfying the following conditions:*

(b1) $d_b(x, y) = 0$ *if and only if* $x = y$,

(b2) $d_b(x, y) = d_b(y, x)$, *for all* $x, y, z \in X$,

(b3) $d_b(x, y) \leq s(d_b(x, z) + d_b(z, y))$ *for all* $x, y, z \in X$, *where* $s \geqq 1$.

The function d_b is called a b-metric and the pair (X, d_b) is called a b-metric space.

EXAMPLE 1. (Berinde, 1993) Let $X = l_p[0, 1]$ be the space of all real functions $\phi(t)$ with $t \in [0, 1]$ such that $\int_0^1 |\phi(t)|^p < +\infty$ with $0 < p < 1$. Define $d_b : X \times X \longrightarrow [0, +\infty)$ as:

$$d_b(\phi, \psi) = \left(\int_0^1 |\phi(t) - \psi(t)|^p dt \right)^{\frac{1}{p}}.$$

Therefore, (X, d_b) is a b-metric space with $s = 2^{\frac{1}{p}}$.

REMARK 2. (Czerwik, 1993) The class of the b-metric space is larger than the class of the metric space. When $s = 1$, the concept of the b-metric space coincides with the concept of the metric space.

In the following we recall the definition of the extended *b*-metric space.

DEFINITION 2. *(Kamran et al, 2017) Let X be a non-empty set and $r : X \times X \longrightarrow [1, +\infty)$. A function $d_r : X \times X \longrightarrow [0, +\infty)$ is called an extended b-metric if for all $x, y, z \in X$ it satisfies the following conditions:*

(b1) $d_r(x, y) = 0$ *if and only if* $x = y$,

(b2) $d_r(x, y) = d_r(y, x)$,

(b3) $d_r(x, y) \leq r(x, y)(d_r(x, z) + d_r(z, y))$.

The pair (X, d_r) is called the extended b-metric space.

Main results

The goal of this section is to describe a few properties and the results of the $b_{(\alpha_n,\beta_n)}$-hypermetric spaces of the dimension n.

$b_{(\alpha_n,\beta_n)}$-hypermetric spaces of the dimension n

Now we first recall and introduce some notation. For $n \geq 2$, let X^n denote the n-times Cartesian product $\underbrace{X \times \ldots \times X}_{n-times}$ and R be an ordered ring. Let $P^*(R)$ denote the family of all non-empty subsets of R. We begin with the following definition.

DEFINITION 3. *Let X be a non-empty set and $\alpha_n, \beta_n : X^n \longrightarrow [1, +\infty)$. Let $\mathbb{U}_{(\alpha_n,\beta_n)} : X^n \longrightarrow P^*(R^+)$ be a function that satisfies the following conditions:*

(U1) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1, \ldots, x_n) = \{0\}$, *if* $x_1 = \ldots = x_n$,

(U2) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1, \ldots, x_n) \supseteq \{0\}$, *for all* $x_1, ..., x_n$ *with* $x_i \neq x_j$, *for some* $i, j \in \{1, ..., n\}$,

(U3) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1, \ldots, x_n) = \mathbb{U}_{(\alpha_n,\beta_n)}(x_{\pi_1}, \ldots, x_{\pi_n})$, *for every permutation* $(\pi_{(1)}, ..., \pi_{(n)})$ *of* $(1, 2, ..., n)$,

(U4) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1, x_2, \ldots, x_{n-1}, x_{n-1}) \subseteq \mathbb{U}_{(\alpha_n,\beta_n)}(x_1, x_2, \ldots, x_{n-1}, x_n)$, *for all* $x_1, \ldots, x_n \in X$,

(U5) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1,x_2,\ldots,x_n) \subseteq \alpha_n(x_1,x_2,\ldots,x_n)\cdot \mathbb{U}_{(\alpha_n,\beta_n)}(x_1,a,...,a)$
$+\,\beta_n(x_1,x_2,\ldots,x_n)\cdot \mathbb{U}_{(\alpha_n,\beta_n)}(a,x_2,...,x_n)$, *for all* $x_1,\ldots,x_n,a \in X$.

Let A_i be the subsets of $X,(i=1,\ldots,n)$, for any $D,D' \in P^*(R^+)$ and $\alpha \in R^+$. We define

$$\mathbb{U}_{(\alpha_n,\beta_n)}(A_1,\ldots,A_n) = \bigcup\Big\{\mathbb{U}_n(x_1,\ldots,x_n) \mid x_i \in A_i, \quad i=1,\ldots,n\Big\},$$

$$D+D' = \{d+d' \mid d\in D, d'\in D'\} \; and \; \alpha\cdot D = \{\alpha\cdot d \mid d\in D, \alpha \in R^+\}.$$

We shall use the following abbreviated notation: The function $\mathbb{U}_n$ is called an *ordered* $b_{(\alpha_n,\beta_n)}$*-hypermetric ring* of the dimension n, or more specifically a $b_{(\alpha_n,\beta_n)}$-hypermetric on X. The pair $(X,\mathbb{U}_n)$ is called an $b_{(\alpha_n,\beta_n)}$-hypermetric space.

For example, we can place $R^+ = \mathbb{Z}^0_+$ or $\mathbb{R}^0_+$, where $\mathbb{Z}^0_+ := \mathbb{N}\cup\{0\} = \{0,1,2,\ldots\}$ and $\mathbb{R}^0_+ := [0,+\infty)$. In the sequel, for simplicity we assume that $R^+ = \mathbb{R}^0_+$. The following useful properties of a b_n-hypermetric are easily derived from the axioms.

REMARK 3. If $\alpha_n(x_1,x_2,\ldots,x_n) = \beta_n(x_1,x_2,\ldots,x_n) = c$ for $c \geq 1$ and $n = 1$, then we obtain the definition of a *b*-metric space (Czerwik, 1993). It is clear that for $c=1$, this *b*-metric becomes a usual metric.

PROPOSITION 1. *(Example) Let* $X=[0,1]$ *and* $\alpha_2,\beta_2 : X\times X \longrightarrow [1,+\infty)$, *with* $\alpha_2(x,y) = 1+\frac{1}{x+y}, \beta_2(x,y) = 1+\frac{2}{x+y}$. *Define*

$$\mathbb{F}_{\alpha_2,\beta_2} : X\times X \to P^*(\mathbb{R}^0_+)$$

with,

$$\mathbb{F}_{(\alpha_2,\beta_2)}(x,y) = \begin{cases} [1,\frac{1}{xy}) & ; \quad x,y\in(0,1],\ x\neq y \\ \{0\} & ; \quad x,y\in[0,1],\ x=y \\ \mathbb{F}_{(\alpha_2,\beta_2)}(y,x) = [1,\frac{1}{x}) & ; \quad y=0, x\in(0,1] \end{cases}$$

and also assume $A+B = A\cup B$, *for all* $A,B\subseteq P(\mathbb{R}^0_+)$. *Then* $(X,\mathbb{F}_{(\alpha_2,\beta_2)})$ *is a* $b_{(\alpha_2,\beta_2)}$*-hypermetric space.*

Proof. It is sufficient to show that $\mathbb{F}_{(\alpha_2,\beta_2)}$ is satisfied in all properties $(U1),(U2),\ldots,(U5)$. The proofs of $(U1),\ldots,(U4)$, follow immediately

from the definition of $\mathbb{F}_{(\alpha_2,\beta_2)}$. We only need to show that $\mathbb{F}_{(\alpha_2,\beta_2)}$ is satisfied in

$$\mathbb{F}_{(\alpha_2,\beta_2)}(x,y) \subseteq \alpha_2(x,y).\mathbb{F}_{(\alpha_2,\beta_2)}(x,z) + \beta_2(x,y).\mathbb{F}_{(\alpha_2,\beta_2)}(z,y), \forall x,y,z \in X.$$

We distinguish the following cases:

(i) Let $x,y \in (0,1]$ For $z \in (0,1]$, we have
$\mathbb{F}_{(\alpha_2,\beta_2)}(x,y) \subseteq \alpha_2(x,y).\mathbb{F}_{(\alpha_2,\beta_2)}(x,z) + \beta_2(x,y).\mathbb{F}_{(\alpha_2,\beta_2)}(z,y)$ if and only if
$[1,\frac{1}{xy}) \subseteq (1+\frac{1}{x+y})[0,\frac{1}{xz}) + (1+\frac{2}{x+y})[0,\frac{1}{zy})$ if and only if $[1,\frac{1}{xy}) \subseteq (1+\frac{2}{x+y})([0,\frac{1}{xz}) + [0,\frac{1}{zy}))$
if and only if $[1,\frac{1}{xy}) \subseteq (\frac{x+y+2}{x+y})[0,\frac{x+y}{xyz})$ if and only if $z \leq 2+x+y$.
If $z = 0$, then $\mathbb{F}_{(\alpha_2,\beta_2)}(x,y) \subseteq \alpha_2(x,y).\mathbb{F}_{(\alpha_2,\beta_2)}(x,0) + \beta_2(x,y).\mathbb{F}_{(\alpha_2,\beta_2)}(0,y)$
if and only if $[1,\frac{1}{xy}) \subseteq (1+\frac{1}{x+y})[0,\frac{1}{x}) + (1+\frac{2}{x+y})[0,\frac{1}{y})$ if and only if $[1,\frac{1}{xy}) \subseteq (1+\frac{2}{x+y})([0,\frac{1}{x})+[0,\frac{1}{y}))$ if and only if $[1,\frac{1}{xy}) \subseteq (\frac{x+y+2}{x+y})[0,\frac{x+y}{xy})$ if and only if $2 \leq 2+x+y$.

(ii) For $x \in (0,1]$ and $y=0$, let $z \in (0,1]$,
$\mathbb{F}_{(\alpha_2,\beta_2)}(x,0) \subseteq \alpha_2(x,0).\mathbb{F}_{(\alpha_2,\beta_2)}(x,z) + \beta_2(x,0).\mathbb{F}_{(\alpha_2,\beta_2)}(z,0)$ if and only if
$[1,\frac{1}{x}) \subseteq (\frac{1+x}{x})[0,\frac{1}{xz}) + (\frac{2+x}{x})[0,\frac{1}{z})$ if and only if $[1,\frac{1}{x}) \subseteq (\frac{2+x}{x})([0,\frac{1}{xz}) + [0,\frac{1}{z}))$ if and only if $[1,\frac{1}{x}) \subseteq (\frac{x+2}{x})[0,\frac{x+1}{xz})$ if and only if $xz \leq (x+1)(x+2)$.

(iii) Let $x,y \in [0,1],\ x=y$. Obviously, $\mathbb{F}_{(\alpha_2,\beta_2)}$ is satisfied in $(U5)$.

Hence $(X,\mathbb{F}_{(\alpha_2,\beta_2)})$ is a $b_{(\alpha_2,\beta_2)}$-hypermetric space. □

PROPOSITION 2. *Let $(X,\mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space, then for any $x_1,...,x_n,a \in X$ it follows that:*

(1) If $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1,...,x_n) = \{0\}$, then $x_1 = ... = x_n$,

(2) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1,...,x_n) \subseteq \sum_{j=2}^{n} \mathbb{U}_{(\alpha_n,\beta_n)}(x_1,...,x_1,x_j)$,

(3) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1,...,x_n) \subseteq \sum_{j=1}^{n} \mathbb{U}_{(\alpha_n,\beta_n)}(x_j,a,...,a)$,

(4) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1,x_2,...,x_2) \subseteq (n-1)\mathbb{U}_{(\alpha_n,\beta_n)}(x_1,...,x_1,x_2)$.

PROPOSITION 3. *Let $(X,\mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space, then $\{0\} \subseteq \mathbb{U}_{(\alpha_n,\beta_n)}(x_1,...,x_n)$ for all $x_1,...,x_n \in X$.*

Proof. By condition $(U4)$ of the definition of a $b_{(\alpha_n,\beta_n)}$-hypermetric space, we have

$$\{0\} = \mathbb{U}_{(\alpha_n,\beta_n)}(x_1, ..., x_1) \subseteq \mathbb{U}_{(\alpha_n,\beta_n)}(x_1, ..., x_n).$$

□

PROPOSITION 4. *Every $b_{(\alpha_n,\beta_n)}$-hypermetric space $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ defines a $b_{(\alpha_2,\beta_2)}$-hypermetric space $(X, \mathbb{U}_{(\alpha_2,\beta_2)})$ as follows:*

$$\mathbb{U}_{(\alpha_2,\beta_2)}(x, y) = \mathbb{U}_{(\alpha_n,\beta_n)}(x, y, \ldots, y) + \mathbb{U}_{(\alpha_n,\beta_n)}(y, x, \ldots, x); \forall x, y \in X.$$

Proof. Note that $(U1), \ldots, (U4)$ trivially hold. We only need to show that $\mathbb{U}_{(\alpha_2,\beta_2)}$ is satisfied in

$$\mathbb{U}_{(\alpha_2,\beta_2)}(x, y) \subseteq \alpha_2(x, y).\mathbb{U}_{(\alpha_2,\beta_2)}(x, z) + \beta_2(x, y).\mathbb{U}_{(\alpha_2,\beta_2)}(z, y), \forall x, y, z \in X.$$

By setting

$$\alpha_2(x, y) = max\{\alpha_n(x, y, ..., y), \alpha_n(y, x, ..., x)\}$$

and

$$\beta_2(x, y) = max\{\beta_n(x, y, ..., y), \beta_n(y, x, ..., x)\}.$$

This completes the proof. □

PROPOSITION 5. *Let e be an arbitrary positive real number, and (X, d) be a metric space. We define an induced $b_{(\alpha_2,\beta_2)}$-hypermetric*

$$\mathbb{U}^e_{(\alpha_2,\beta_2)} : X \times X \to P^*(\mathbb{R}^0_+)$$

$$\mathbb{U}^e_{(\alpha_2,\beta_2)}(x, y) = \begin{cases} \big(d(x, y) - e, d(x, y) + e\big) \cup \{0\}; & x \neq y, d(x, y) > e \\ \big(d(x, y) - e, d(x, y) + e\big) \cap \mathbb{R}^0_+; & x \neq y, d(x, y) < e \\ \{0\}; & x = y \text{ or } d(x, y) = e. \end{cases}$$

Then $(X, \mathbb{U}^e_{(\alpha_2,\beta_2)})$ is a $b_{(\alpha_2,\beta_2)}$-hypermetric space.

Quotient $b_{(\alpha_n,\beta_n)}$-hypermetric space

Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space and $\widetilde{X}$ be a partition of X. For each point $p \in X$, we denote $\widetilde{p}$ a point in $\widetilde{X}$ containing p, and we denote the equivalent relation induced by the relation by $\sim$.

DEFINITION 4. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space. Let $p_1, \ldots, p_n \in X$, and consider $\widetilde{p_1}, \ldots, \widetilde{p_n} \in \widetilde{X}$. A quotient $b_{(\alpha_n,\beta_n)}$-hypermetric of points of $\widetilde{X}$ induced by $\mathbb{U}_{(\alpha_n,\beta_n)}$ is the function*

$$\widetilde{\mathbb{U}}_{(\alpha_n,\beta_n)} : \widetilde{X}^n \longrightarrow P^*(\mathbb{R}^0_+)$$

given by

$$\widetilde{\mathbb{U}}_{(\alpha_n,\beta_n)}(\widetilde{p_1}, \ldots, \widetilde{p_n}) = \bigcap_{p_i \in \widetilde{p_i}} \mathbb{U}_{(\alpha_n,\beta_n)}(p_1, \ldots, p_n).$$

PROPOSITION 6. *The quotient $b_{(\alpha_n,\beta_n)}$-hypermetric induced by $\mathbb{U}_{(\alpha_n,\beta_n)}$ is well defined and is a $b_{(\alpha_n,\beta_n)}$-hypermetric on $\widetilde{X}$.*

Proof. $\widetilde{\mathbb{U}}_{(\alpha_n,\beta_n)}$ is satisfied in all properties $(U1)$, till $(U4)$,

$$\widetilde{\mathbb{U}}_{(\alpha_n,\beta_n)}(\widetilde{p_1}, \ldots, \widetilde{p_n}) \subseteq \widetilde{\mathbb{U}}_{(\alpha_n,\beta_n)}(\widetilde{p_1}, \widetilde{q}, \ldots, \widetilde{q}) + \mathbb{U}_{(\alpha_n,\beta_n)}(\widetilde{q}, \widetilde{p_2}, \ldots, \widetilde{p_n})$$

$$\bigcap_{p_i \in \widetilde{P_i}} \mathbb{U}_{(\alpha_n,\beta_n)}(p_1, \ldots, p_n) \subseteq$$
$$\bigcap_{\substack{p_i \in \widetilde{P_i} \\ q \in \widetilde{q}}} \Big(\mathbb{U}_{(\alpha_n,\beta_n)}(p_1, q, \ldots, q) + \mathbb{U}_{(\alpha_n,\beta_n)}(q, p_2, \ldots, p_n) \Big)$$

$$= \bigcap_{\substack{p_i \in \widetilde{P_i} \\ q \in \widetilde{q}}} \mathbb{U}_{(\alpha_n,\beta_n)}(p_1, q, \ldots, q) + \bigcap_{\substack{p_i \in \widetilde{P_i} \\ q \in \widetilde{q}}} \mathbb{U}_{(\alpha_n,\beta_n)}(q, p_2, \ldots, p_n)$$

$$= \bigcap_{\substack{p_i \in \widetilde{P_i} \\ q \in \widetilde{q}}} \Big(\mathbb{U}_{(\alpha_n,\beta_n)}(p_1, q, \ldots, q) + \mathbb{U}_{(\alpha_n,\beta_n)}(q, p_2, \ldots, p_n) \Big).$$

□

Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space of a dimension $n > 2$. For any arbitrary a in X, define the function $\mathbb{U}_{(\alpha_{n-1},\beta_{n-1})}$ on X^{n-1} by $\mathbb{U}_{(\alpha_{n-1},\beta_{n-1})}(x_1, \ldots, x_{n-1}) := \mathbb{U}_{(\alpha_n,\beta_n)}(x_1, \ldots, x_{n-1}, a)$.
Then we have the following result.

PROPOSITION 7. *The function* $\mathbb{U}_{(\alpha_{n-1},\beta_{n-1})}$ *define a* $b_{(\alpha_{n-1},\beta_{n-1})}$*-hypermetric on* X*.*

Proof. We will verify that $\mathbb{U}_{(\alpha_{n-1},\beta_{n-1})}$ satisfies the five properties of a $b_{(\alpha_{n-1},\beta_{n-1})}$-hypermetric. □

PROPOSITION 8. *Let* $\Pi : X \to Y$ *be an injection from a set* X *to a set* Y*. If* $\mathbb{U}_{(\alpha_n,\beta_n)} : Y^n \to P^*(\mathbb{R}^0_+)$ *is a* $b_{(\alpha_n,\beta_n)}$*-hypermetric on the set* Y*. Then* $\overline{\mathbb{U}}_{(\alpha_n,\beta_n)} : X^n \to P^*(\mathbb{R}^0_+)$*, given by the formula* $\overline{\mathbb{U}}_{(\alpha_n,\beta_n)}(x_1,\ldots,x_n) = \mathbb{U}_{(\alpha_n,\beta_n)}(\Pi(x_1),\ldots,\Pi(x_n))$ *for all* $x_1,\ldots,x_n \in X$*, is a* $b_{(\alpha_n,\beta_n)}$*-hypermetric on the set* X*.*

PROPOSITION 9. *Let* $(X,\mathbb{U}_{(\alpha_n,\beta_n)})$ *be any* $b_{(\alpha_n,\beta_n)}$*-hypermetric space and* $\lambda \in \mathbb{R}^0_+$*. Then* $(X,\mathbb{U}^{\lambda}_{(\alpha_n,\beta_n)})$ *is also a* $b_{(\alpha_n,\beta_n)}$*-hypermetric space where* $\mathbb{U}^{\lambda}_{(\alpha_n,\beta_n)}(x_1,\ldots,x_n) := \{A \cap [0,\lambda) | A \in \mathbb{U}_{(\alpha_n,\beta_n)}(x_1,\ldots,x_n)\}$.

So, on the same X many intances of the $b_{(\alpha_n,\beta_n)}$-hypermetric can be defined, as a result of which the same set X is endowed with different metric structures. Another structure in the next proposition is useful for scaling the $b_{(\alpha_n,\beta_n)}$-hypermetric, so we need the following explanation.

For any non-empty subset A of $\mathbb{R}^0_+$, and $\lambda \in \mathbb{R}^+$ we define a set $\lambda \cdot A$ to be $\lambda \cdot A := \{\lambda \cdot a \mid a \in A\}$.

PROPOSITION 10. *Let* $(X,\mathbb{U}_{(\alpha_n,\beta_n)})$ *be any* $b_{(\alpha_n,\beta_n)}$*-hypermetric space. Let* Λ *be any positive real number. We define* $\dot{\mathbb{U}}^{\Lambda}_{(\alpha_n,\beta_n)}(x_1,\ldots,x_n) = \lambda.\mathbb{U}_{(\alpha_n,\beta_n)}(x_1,\ldots,x_n)$*. Then* $(X,\dot{\mathbb{U}}^{\lambda}_{(\alpha_n,\beta_n)})$*is also a* $b_{(\alpha_n,\beta_n)}$*-hypermetric space.*

A sequence $\{x_m\}$ in a $b_{(\alpha_n,\beta_n)}$-hypermetric space $(X,\mathbb{U}_{(\alpha_n,\beta_n)})$ is said to converge to a point s in X, if for any $\epsilon > 0$ there exists a natural number N such that for every $m_1,\ldots,m_{n-1} \geq N$

$$\mathbb{U}_{(\alpha_n,\beta_n)}(x_{m_1},...,x_{m_{n-1}},s) \subseteq [0,\epsilon),$$

then we shall write

$$\lim_{m_1,\ldots,m_{n-1}\longrightarrow+\infty} \mathbb{U}_{(\alpha_n,\beta_n)}(x_{m_1},...,x_{m_{n-1}},s) = \{0\}.$$

We shall say that a sequence $\{x_m\}$ has a cluster point x if there exists a subsequence $\{x_{m_k}\}$ of $\{x_m\}$ that converges to x.

PROPOSITION 11. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ and $(X', \mathbb{U}'_{(\alpha_n,\beta_n)})$ be two $b_{(\alpha_n,\beta_n)}$-hypermetric spaces. Then a function $T : X \to X'$ is $b_{(\alpha_n,\beta_n)}$-continuous at a point $x \in X$, if and only if it is $b_{(\alpha_n,\beta_n)}$-sequentially continuous at x; that is, whenever sequence $\{x_m\}$ is $b_{(\alpha_n,\beta_n)}$-convergent to x one has $\{T(x_m)\}$ is $U_{(\alpha_n,\beta_n)}$-convergent to $T(x)$.*

DEFINITION 5. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space, and $A \subseteq X$. The set A is $b_{(\alpha_n,\beta_n)}$-compact if for every $b_{(\alpha_n,\beta_n)}$-sequence $\{x_m\}$ in A, there exists a subsequence $\{x_{m_k}\}$ of $\{x_m\}$ such that $b_{(\alpha_n,\beta_n)}$-convergences to some $x_0 \in A$.*

PROPOSITION 12. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ and $(X', \mathbb{U}'_{(\alpha_n,\beta_n)})$ be two $b_{(\alpha_n,\beta_n)}$-hypermetric spaces and $T : X \to X'$ a $b_{(\alpha_n,\beta_n)}$-continuous function on X. If X is $b_{(\alpha_n,\beta_n)}$-compact, then $T(X)$ is $b_{(\alpha_n,\beta_n)}$-compact.*

DEFINITION 6. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space, then for $x_0 \in X$, $r > 0$, the $b_{(\alpha_n,\beta_n)}$-hyperball with the centre x_0 and the radius r is*

$$B_{\mathbb{U}_{(\alpha_n,\beta_n)}}(x_0, r) = \{y \in X : \mathbb{U}_{(\alpha_n,\beta_n)}(x_0, y, ..., y) \subseteq [0, r)\}.$$

PROPOSITION 13. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space, then for $x_0 \in X$, $r > 0$,*
(i) If $\mathbb{U}_{(\alpha_n,\beta_n)}(x_0, x_2, ..., x_n) \subseteq [0, r)$, then $x_2, ..., x_n \in B_{\mathbb{U}_{(\alpha_n,\beta_n)}}(x_0, r)$,
(ii) If $y \in B_{\mathbb{U}_{(\alpha_n,\beta_n)}}(x_0, r)$, then there exists, $\delta > 0$ such that $B_{\mathbb{U}_{(\alpha_n,\beta_n)}}(y, \delta) \subseteq B_{\mathbb{U}_{(\alpha_n,\beta_n)}}(x_0, r)$.

PROPOSITION 14. *The set of all $\mathbb{U}_{(\alpha_n,\beta_n)}$-balls, $\mathcal{B}_n = \{B_{\mathbb{U}_{(\alpha_n,\beta_n)}}(x, r) : x \in X, r > 0\}$, forms a basis for a topology $\mathcal{T}(\mathbb{U}_{(\alpha_n,\beta_n)})$ on X.*

DEFINITION 7. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space. The sequence $\{x_n\} \subseteq X$ is $b_{(\alpha_n,\beta_n)}$-convergent to x if it $b_{(\alpha_n,\beta_n)}$-converges to x in the $b_{(\alpha_n,\beta_n)}$-hypermetric topology, $\mathcal{T}(\mathbb{U}_{(\alpha_n,\beta_n)})$.*

PROPOSITION 15. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space. Then for a sequence $\{x_m\} \subseteq X$, and a point $x \in X$ the following are equivalent:*
(1) $\{x_m\}$ is $\mathbb{U}_{(\alpha_n,\beta_n)}$-convergent to x,

(2) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_m, ..., x_m, x) \to 0$*, and*
(3) $\mathbb{U}_{(\alpha_n,\beta_n)}(x_m, x, ..., x) \to 0$*.*

DEFINITION 8. *Let* $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$*,* $(Y, \mathbb{V}_{(\alpha_m,\beta_m)})$ *be universal hypermetric spaces of the dimensions* n *and* m *respectively; a function* $T : X \longrightarrow Y$ *is* $b_{(\alpha_n,\beta_n),(\alpha_m,\beta_m)}$*-continuous at the point* $x_0 \in X$*, if* $T^{-1}(B_{\mathbb{V}_{(\alpha_m,\beta_m)}}(T(x_0), r)) \in \mathcal{T}(U_n)$*, for all* $r > 0$*.*

We say f *is* $b_{(\alpha_n,\beta_n),(\alpha_m,\beta_m)}$*-continuous if it is* $b_{(\alpha_n,\beta_n),(\alpha_m,\beta_m)}$*-continuous at all points of* X*; that is, continuous as a function from* X *with the* $\mathcal{T}(\mathbb{U}_{(\alpha_n,\beta_n)})$*-topology to* Y *with the* $\mathcal{T}(\mathbb{V}_{(\alpha_m,\beta_m)})$*-topology.*

In the sequel, for simplicity we have assumed that $n = m$. Since $b_{(\alpha_n,\beta_n)}$-hypermetric topologies are metric topologies, we have:

DEFINITION 9. *Let* $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ *and* $(Y, \mathbb{V}_{(\alpha_n,\beta_n)})$ *be two* $b_{(\alpha_n,\beta_n)}$*-hypermetric spaces and* $T : (X, \mathbb{U}_{(\alpha_n,\beta_n)}) \to (Y, \mathbb{V}_{(\alpha_n,\beta_n)})$ *be a function. The function* f *is called* $b_{(\alpha_n,\beta_n)}$*-continuous at a point* $a \in X$ *if and only if, for given* $\epsilon > 0$*, there exists* $\delta > 0$ *such that* $x_1, \ldots, x_{n-1} \in X$ *and the subset relation* $\mathbb{U}_{(\alpha_n,\beta_n)}(a, x_1, \ldots, x_{n-1}) \subseteq [0, \delta)$ *implies that* $\mathbb{V}_{(\alpha_n,\beta_n)}(T(a), T(x_1), \ldots, T(x_{n-1})) \subseteq [0, \epsilon)$*.*

A function f *is* $b_{(\alpha_n,\beta_n)}$*-continuous on* X *if and only if it is* $b_{(\alpha_n,\beta_n)}$*-continuous at all* $a \in X$

PROPOSITION 16. *Let* $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$*,* $(Y, \mathbb{V}_{(\alpha_n,\beta_n)})$ *be* $b_{(\alpha_n,\beta_n)}$*-hypermetric spaces, a function* $T : X \longrightarrow Y$ *is* $b_{(\alpha_n,\beta_n)}$*-continuous at point* $x \in X$ *if and only if it is* $b_{(\alpha_n,\beta_n)}$*-sequentially continuous at* x*; that is, whenever the* $\{x_n\}$ *is* $b_{(\alpha_n,\beta_n)}$*-convergent to* x *we have* $(T(x_n))$ *is* $b_{(\alpha_n,\beta_n)}$*-convergent to* $T(x)$*.*

PROPOSITION 17. *Let* $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ *be a* $b_{(\alpha_n,\beta_n)}$*-hypermetric space. Then the function*
$\mathbb{U}_{(\alpha_n,\beta_n)}(z_1, z_2, ..., z_n)$ *is jointly* $b_{(\alpha_n,\beta_n)}$*-continuous in all* n *of its variables.*

DEFINITION 10. *A map* $T : X \longrightarrow Y$ *between* $b_{(\alpha_n,\beta_n)}$*-hypermetric spaces* $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ *and* $(Y, \mathbb{U}'_{(\alpha_n,\beta_n)})$ *is an iso-hypermetric when* $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1, ..., x_n) = \mathbb{U}'_{(\alpha_n,\beta_n)}(T(x_1), ..., T(x_n))$ *for all* $x_1, \ldots, x_n \in X$*. If the iso-*$b_{(\alpha_n,\beta_n)}$*-hypermetric is injective, we call it iso-*$b_{(\alpha_n,\beta_n)}$*-hypermetric em-*

bedding. A bijective iso-$b_{(\alpha_n,\beta_n)}$-hypermetric is called a $b_{(\alpha_n,\beta_n)}$-hypermetric isomorphism.

Fixed Point Theorem in $b_{(\alpha_n,\beta_n)}$-hypermetric spaces

In a $b_{(\alpha_n,\beta_n)}$-hypermetric space, the concepts of basic topological notions, such as: $b_{(\alpha_n,\beta_n)}$-Cauchy sequence, $b_{(\alpha_n,\beta_n)}$-convergent sequence and $b_{(\alpha_n,\beta_n)}$-complete $b_{(\alpha_n,\beta_n)}$-hypermetric space can be easily adopted as shown below. We discuss about the concept of $b_{(\alpha_n,\beta_n)}$-completeness of $b_{(\alpha_n,\beta_n)}$-hypermetric spaces.

DEFINITION 11. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ be a $b_{(\alpha_n,\beta_n)}$-hypermetric space, then a sequence $\{x_m\} \subseteq X$ is called $b_{(\alpha_n,\beta_n)}$-Cauchy if for every $\varepsilon > 0$, there exists $N \in \mathbb{N}$ such that $\mathbb{U}_{(\alpha_n,\beta_n)}(x_{m_1}, x_{m_2}, ..., x_{m_n}) < \varepsilon$ for all $m_1, m_2, ..., m_n \geq N$.*

The next proposition follows directly from the definitions.

PROPOSITION 18. *In a $b_{(\alpha_n,\beta_n)}$-hypermetric space, $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$, the following are equivalent.*
(i) The sequence $\{x_m\}$ is $b_{(\alpha_n,\beta_n)}$-Cauchy.
(ii) For every $\varepsilon > 0$, there exists $N \in \mathbb{N}$ such that $\mathbb{U}_{(\alpha_n,\beta_n)}(x_l, x_m, ..., x_m) < \varepsilon$, for all $l, m \geq N$.
(iii) $\{x_m\}$ is a Cauchy sequence in the metric space $(X, d_{\mathbb{U}_{(\alpha_n,\beta_n)}})$.

COROLLARY 1. ***(i)*** *Every $b_{(\alpha_n,\beta_n)}$-convergent sequence in a $b_{(\alpha_n,\beta_n)}$-hypermetric space is $b_{(\alpha_n,\beta_n)}$-Cauchy.*
(ii) *If a $b_{(\alpha_n,\beta_n)}$-Cauchy sequence in a $b_{(\alpha_n,\beta_n)}$-hypermetric space $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ contains a $b_{(\alpha_n,\beta_n)}$-convergent subsequence, then the sequence itself is $b_{(\alpha_n,\beta_n)}$-convergent.*

DEFINITION 12. *A $b_{(\alpha_n,\beta_n)}$-hypermetric space $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ is called $b_{(\alpha_n,\beta_n)}$-complete if every $b_{(\alpha_n,\beta_n)}$-Cauchy sequence in $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ is $b_{(\alpha_n,\beta_n)}$-convergent in $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$.*

PROPOSITION 19. *A $b_{(\alpha_n,\beta_n)}$-hypermetric space $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ is $b_{(\alpha_n,\beta_n)}$-complete if and only if $(X, d_{\mathbb{U}_{(\alpha_n,\beta_n)}})$ is a complete metric space.*

DEFINITION 13. *Let $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ and $(Y, \mathbb{U}'_{(\alpha_n,\beta_n)})$ be two $b_{(\alpha_n,\beta_n)}$-hypermetric spaces. A function $f : X \longrightarrow Y$ is called a $b_{(\alpha_n,\beta_n)}$-contraction*

if there exists a constant $k \in [0,1)$ *such that* $\mathbb{U}'_{(\alpha_n,\beta_n)}(f(x_1),...,f(x_n)) = k\mathbb{U}_{(\alpha_n,\beta_n)}(x_1,...,x_n)$ *for all* $x_1,\ldots,x_n \in X$.

It follows that f is $b_{(\alpha_n,\beta_n)}$-continuous because; $\mathbb{U}_{(\alpha_n,\beta_n)}(x_1,...,x_n) \subseteq [0,\delta)$ with $k \neq 0$ and $\delta := \epsilon/k$ implies $\mathbb{U}'_{(\alpha_n,\beta_n)}(f(x_1),...,f(x_n)) \subseteq [0,\epsilon)$.

THEOREM 1. *Let* $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$ *be a* $b_{(\alpha_n,\beta_n)}$*-complete space and let* $T : X \to X$ *be a* $b_{(\alpha_n,\beta_n)}$*-contraction map. Then* T *has a unique fixed point* $T(x) = x$.

Proof. We consider $x_{m+1} = T(x_m)$, with x_0 being any point in X. By repeated use of the (α_n, β_n)-rectangle inequality and the application of the contraction property, we obtain

$$\mathbb{U}_{(\alpha_n,\beta_n)}(x_m, x_{m+1}, \ldots, x_{m+1}) \subseteq k^m \mathbb{U}_{(\alpha_n,\beta_n)}(x_0, x_1, \ldots, x_1)$$

for all $m, s_1 \in \mathbb{N}$ which $m < s_1$ and $k \in [0,1)$. It follows from the above that

$$\begin{aligned}
\mathbb{U}_{(\alpha_n,\beta_n)}(x_m, x_{s_1}, \ldots, x_{s_1}) &\subseteq \Gamma_1 \mathbb{U}_{(\alpha_n,\beta_n)}(x_m, x_{m+1}, \ldots, x_{m+1}) \\
&\quad + \Gamma_2 \mathbb{U}_{(\alpha_n,\beta_n)}(x_{m+1}, x_{m+2}, \ldots, x_{m+2}) \\
&\quad + \Gamma_3 \mathbb{U}_{(\alpha_n,\beta_n)}(x_{m+2}, x_{m+3}, \ldots, x_{m+3}) \\
&\quad + \ldots + \Gamma_{s_1-m} \mathbb{U}_{(\alpha_n,\beta_n)}(x_{s_1-1}, x_{s_1}, \ldots, x_{s_1}) \\
&\subseteq \Gamma(k^m + k^{m+1} + \ldots + k^{s_1-1}) \mathbb{U}_{(\alpha_n,\beta_n)}(x_0, x_1, \ldots, x_1) \\
&= \Gamma \frac{k^m(1-k^{s_1-m})}{1-k} \mathbb{U}_{(\alpha_n,\beta_n)}(x_0, x_1, \ldots, x_1)
\end{aligned}$$

where $\Gamma_1 = \alpha_n(x_m, x_{s_1}, \ldots, x_{s_1})$,
$\Gamma_2 = \beta_n(x_m, x_{s_1}, \ldots, x_{s_1}) \cdot \alpha_n(x_m, x_{m+1}, \ldots, x_{m+1}), ...$
and $\Gamma = max\{\Gamma_1, \Gamma_2, ..., \Gamma_{s_1-m}\}$ for all $x_m, ..., x_{s_1} \in B_{\mathbb{U}_{(\alpha_n,\beta_n)}}(x_0, r)$.

Then we have

$$\lim_{m\,,\,s_1 \to +\infty} \mathbb{U}_{(\alpha_n,\beta_n)}(x_m, x_{s_1}, \ldots, x_{s_1}) = \{0\}$$

since

$$\lim_{m\,,\,s_1 \to +\infty} \Gamma \frac{k^m(1-k^{s_1-m})}{1-k} \mathbb{U}_{(\alpha_n,\beta_n)}(x_0, x_1, \ldots, x_1) = \{0\}.$$

For $m \leq s_1 \leq s_2 \in \mathbb{N}$ and $(U5)$ it implies that

$$\mathbb{U}_{(\alpha_n,\beta_n)}(x_m, x_{s_1}, x_{s_2} \ldots, x_{s_2}) \subseteq$$

$$\alpha_n(x_m, x_{s_1}, x_{s_2} \ldots, x_{s_2})\mathbb{U}_{(\alpha_n,\beta_n)}(x_m, x_{s_1}, \ldots, x_{s_1})$$
$$+\beta_n(x_m, x_{s_1}, x_{s_2} \ldots, x_{s_2})\mathbb{U}_{(\alpha_n,\beta_n)}(x_{s_1}, x_{s_2}, \ldots, x_{s_2}),$$

now taking a limit as $m, s_1, s_2 \to +\infty$, we get

$$\mathbb{U}_{(\alpha_n,\beta_n)}(x_m, x_{s_1}, x_{s_2} \ldots, x_{s_2}) \to \{0\}.$$

Now for $m \leq s_1 \leq s_2 \leq \ldots \leq s_{n-1} \in \mathbb{N}$, we will have

$$\mathbb{U}_{(\alpha_n,\beta_n)}(x_m, x_{s_1}, \ldots, x_{s_n}) \to \{0\}; \quad whenever, \quad m, s_1, \ldots, s_{n-1} \to +\infty,$$

then $\{x_m\}$ is a Cauchy sequence. By completeness of $(X, \mathbb{U}_{(\alpha_n,\beta_n)})$, there exists $a \in X$ such that $\{x_n\}$ is $b_{(\alpha_n,\beta_n)}$-convergent to a. It follows that the limit x_m is a fixed point of T following the $b_{(\alpha_n,\beta_n)}$-continuity of T, and

$$Ta = T \lim_{m\to+\infty} x_m = \lim_{m\to+\infty} Tx_m = \lim_{m\to+\infty} x_{m+1} = a.$$

Finally, if a and b are two fixed points, then

$$\begin{aligned} \{0\} \subseteq \mathbb{U}_{(\alpha_n,\beta_n)}(a, b, \ldots, b) &= \mathbb{U}_{(\alpha_n,\beta_n)}\Big(T(a), T(b), \ldots, T(b)\Big) \\ &\subseteq k\mathbb{U}_{(\alpha_n,\beta_n)}(a, b, \ldots, b). \end{aligned}$$

We conclude from $k < 1$ that $\mathbb{U}_n(a, b, \ldots, b) = \{0\}$. Consequently, $a = b$ and the fixed point is unique. □

Conclusion

The objective of this paper is to bring about the study of $b_{(\alpha_n,\beta_n)}$-hypermetric spaces and to introduce certain fixed point results of mappings in the setting of $b_{(\alpha_n,\beta_n)}$-hypermetric spaces. This study presents the initial results in this topic and more refined results can be derived in the near future. Also in the future, we will consider engineering applications of the considered topic.

References

Agarwal, R.P., Karapinar, E, O'Regan, D. & Roldán-López-de-Hierro, A.F. 2015. *Fixed Point Theory in Metric Type Spaces*. Springer International Publishing Switzerland. Available at: https://doi.org/10.1007/978-3-319-24082-4. ISBN: 978-3-319-24082-4.

Bakhtin, I. 1989. The contraction mapping principle in quasimetric spaces. *Func. An., Gos. Ped. Inst. Unianowsk*, 30, pp.26-37.

Berinde, V. 1993. Generalized contractions in quasimetric spaces. *Seminar on Fixed Point Theory*, 3(9), pp.3-9 [online]. Available at: https://www.researchgate.net/profile/Vasile-Berinde/publication/267016246_Generalized_contractions_in_quasimetric_spaces/links/559a0dd908ae5d8f39364ab8/Generalized-contractions-in-quasimetric-spaces.pdf [Accessed: 1 December 2021].

Czerwik, S. 1993. Contraction mappings in b-metric spaces. *Acta Mathematica et Informatica Universitatis Ostraviensis*, 1, pp.5-11 [online]. Available at: https://dml.cz/handle/10338.dmlcz/120469 [Accessed: 1 December 2021].

Debnath, P., Konwar, N. & Radenović, S. 2021. *Metric Fixed Point Theory: Applications in Science, Engineering and Behavioural Sciences*. Springer Verlag, Singapore. ISBN-13: 978-9811648953.

Dehghan Nezhad, A. & Aral, Z. 2011. The topology of GB-metric spaces. *International Scholarly Research Notices*, art.ID:523453. Available at: https://doi.org/10.5402/2011/523453.

Dehghan Nezhad, A., Forough, A., Mirkov, N. & Radenović, S. 2021. A new version of U_n-hypermetric space results. *Vojnotehnički glasnik/Military Technical Courier*, 69(3), pp.562-577. Available at: https://doi.org/10.5937/vojtehg69-32197.

Dehghan Nezhad, A. & Khajuee, N. 2013. Some new results on complete $\mathbb{U}_n^*$-metric space. *Journal of Nonlinear Sciences and Applications*, 6(3), pp.216-226. Available at: http://dx.doi.org/10.22436/jnsa.006.03.07.

Dehghan Nezhad, A., Khajuee, N. & Mustafa, Z. 2017. Some new results on Universal metric spaces. *Thai Journal of Mathematics*, 15(2), pp.429-449 [online]. Available at: http://thaijmath.in.cmu.ac.th/index.php/thaijmath/article/view/623 [Accessed: 1 December 2021].

Dehghan Nezhad, A. & Mazaheri, H. 2010. New results in G-best approximation in G-metric spaces. *Ukrainian Mathematical Journal*, 62(4), pp.648-654. Available at: https://doi.org/10.1007/s11253-010-0377-8.

Dhage, B.C., Pathan, A.M. & Rhoades, B.E. 2000. A general existence principle for fixed point theorems in d-metric spaces. *International Journal of Mathematics and Mathematical Sciences*, 23(7), art.ID:695952, pp.441-448. Available at: https://doi.org/10.1155/S0161171200001587.

Gähler, S. 1963. 2-metrische Räume und ihre topologische Struktur. *Mathematische Nachrichten*, 26(1-4), pp.115-148. Available at: https://doi.org/10.1002/mana.19630260109.

Kamran, T., Samreen, M. & UL Ain, Q. 2017. A Generalization of b-Metric Space and Some Fixed Point Theorems. *Mathematics*, 5(2), art.number:19, pp.1-7. Available at: https://doi.org/10.3390/math5020019.

Khan, K.A. 2012. On the possibitity of n-topological spaces. *International Journal of Mathematical Archive*, 3(7), pp.2520-2523 [online]. Available at: http://www.ijma.info/index.php/ijma/article/view/1442 [Accessed: 1 December 2021].

Khan, K.A. 2014. Generalized n-metric spaces and fixed point theorems. *Journal of Nonlinear and Convex Analysis*, 15(6), pp.1221-1229 [online]. Available at: http://www.yokohamapublishers.jp/online2/jncav15.html [Accessed: 1 December 2021].

Kirk, W. & Shahzad, N. 2014. *Fixed Point Theory in Distance Spaces*. Springer International Publishing Switzerland. Available at: https://doi.org/10.1007/978-3-319-10927-5. ISBN: 978-3-319-10927-5.

Mustafa, Z. & Sims, B. 2003. Some remarks concerning D-metric spaces. In: *Proceeding of the International Conferences on Fixed Point Theory and Applications*, Valencia (Spain), pp.189-198, July 13-18. Available at: https://carma.edu.au/brailey/Research_papers/Some%20Remarks%20Concerning%20D%20-%20Metric%20Spaces.pdf [Accessed: 10 May 2021].

Mustafa, Z. & Sims, B. 2006. A new approach to generalized metric spaces. *Journal of Nonlinear Convex Analysis*, 7(2), pp.289-297 [online]. Available at: https://carma.edu.au/brailey/Research_papers/A%20new%20Approach%20to%20Generalized%20Metric%20Spaces.pdf [Accessed: 10 May 2021].

Todorčević, V. 2019. *Harmonic Quasiconformal Mappings and Hyperbolic Type Metrics*. Springer Nature Switzerland AG. Available at: https://doi.org/10.1007/978-3-030-22591-9. ISBN: 978-3-030-22591-9.

Younis, M., Singh, D., Altun, I. & Chauhan, V. 2021a. Graphical structure of extended b-metric spaces: an application to the transverse oscillations of a homogeneous bar. *International Journal of Nonlinear Sciences and Numerical Simulation*, 2021, art.ID:000010151520200126. Available at: https://doi.org/10.1515/ijnsns-2020-0126.

Younis, M., Singh, D. & Abdou, A.N.A. 2021b. A fixed point approach for tuning circuit problem in dislocated b-metric spaces. *Mathematical Methods in the Applied Sciences*, 2021, pp.1-20. Available at: https://doi.org/10.1002/mma.7922.

Younis, M., Singh, D. & Shi, L. 2021c. Revisiting graphical rectangular b-metric spaces. *Asian-European Journal of Mathematics*, 2021, art.number:2250072. Available at: https://doi.org/10.1142/S1793557122500723.

Younis, M. & Singh, D. 2021. On the existence of the solution of Hammerstein integral equations and fractional differential equations. *Journal of Applied Mathematics and Computing*, 2021. Available at: https://doi.org/10.1007/s12190-021-01558-1.

ИНОЙ ПОДХОД К $b_{(\alpha_n,\beta_n)}$-ГИПЕРМЕТРИЧЕСКИМ ПРОСТРАНСТВАМ

Акбар Дехгхан Незхад[а], *Никола* Мирков[б],
Весна Тодорчевич[в], *Стоян* Раденович[г]

[а] Иранский университет науки и технологий, математический факультет, Нармак, г. Тегеран, Исламская Республика Иран, **корреспондент**

[б] Белградский университет, Институт ядерных исследований «Винча» - Институт национального значения для Республики Сербия, г. Белград, Республика Сербия

[в] Белградский университет, факультет организационных наук, г. Белград, Республика Сербия

[г] Белградский университет, машиностроительный факультет, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА;
27.25.17 Метрическая теория функций,
27.39.15 Линейные пространства, снабженные топологией, порядком и другими структурами

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Целью данной статьи является представление концепции $b_{(\alpha_n,\beta_n)}$-гиперметрических пространств.

Методы: В статье применены конвенциональные теоретические методы функционального анализа.

Результаты: В статье представлены инициальные результаты в области $b_{(\alpha_n,\beta_n)}$-гиперметрических пространств. В первой части обобщается n-мерное $(n \geq 2)$ гиперметрическое расстояние на произвольном непустом множестве X. Функцию $b_{(\alpha_n,\beta_n)}$-гиперрастояния можно определить произвольно при наличии трех свойств: не отрицательность, положительная определенность, симметрия и (α_n, β_n)- неравенство треугольника. Во второй части статьи рассматривается концепция (α_n, β_n)-полноты по отношению к $b_{(\alpha_n,\beta_n)}$-гиперметрике и теореме о неподвижной точке, которая играет важную роль в прикладной математике в нескольких областях.

Выводы: С помощью соответствующих обобщений можно сформулировать известные результаты классических метрических пространств в случае $b_{(\alpha_n,\beta_n)}$-гиперметрических пространств.

Ключевые слова: $b_{(\alpha_n,\beta_n)}$-гиперметрические пространства, G-метрика, неподвижные точки.

ДРУГАЧИЈИ ПРИСТУП ПРЕМА $b_{(\alpha_n,\beta_n)}$-ХИПЕРМЕТРИЧКИМ ПРОСТОРИМА

Акбар Дегхан Незхад[а], *Никола* Мирков[б], *Весна* Тодорчевић[в], *Стојан* Раденовић[г]

[а] Ирански универзитет науке и технологије, Математички факултет, Нармак, Техеран, Исламска Република Иран

[б] Универзитет у Београду, Институт за нуклеарне науке „Винча" – Институт од националног значаја за Републику Србију, Београд, Република Србија, **аутор за преписку**

[в] Универзитет у Београду, Факултет организационих наука, Београд, Република Србија

[г] Универзитет у Београду, Машински факултет, Београд, Република Србија

ОБЛАСТ: математика
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Циљ овог рада јесте да се представи концепт $b_{(\alpha_n,\beta_n)}$-хиперметричких простора.

Методе: Примењене су конвенционалне теоретске методе функционалне анализе.

Резултати: У раду су представљени иницијални резултати који се односе на $b_{(\alpha_n,\beta_n)}$-хиперметричке просторе. У првом делу генерализује се n-димензионално $(n \geq 2)$ хиперметричко растојање на произвољном непразном скупу X. Функција $b_{(\alpha_n,\beta_n)}$-хиперрастојања може се дефинисати на произвољан начин докле год су задовољене три особине: ненегативност, позитивна дефинитност, симетрија и (α_n,β_n)-неједнакост троугла. У другом делу рада разматрани су концепт (α_n,β_n)-комплетности у односу на $b_{(\alpha_n,\beta_n)}$)-хиперметрику и теорема фиксне тачке, која има значајну улогу у примењеној математици на више поља.

Закључак: Одговарајућим генерализацијама могуће је формулисати познате резултате класичних метричких простора на случај $b_{(\alpha_n,\beta_n)}$-хиперметричких простора.

Кључне речи: $b_{(\alpha_n,\beta_n)}$-хиперметрички простори, G-метрика, фиксне тачке.

Paper received on / Дата получения работы / Датум пријема чланка: 08.12.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 04.01.2022.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 05.01.2022.

HARMONIC SERIES WITH POLYLOGARITHMIC FUNCTIONS

Vuk Stojiljković[a], *Nicola* Fabiano[b], *Vesna* Šešum Čavić[c]

[a] University of Novi Sad, Faculty of Sciences,
Novi Sad, Republic of Serbia,
e-mail: vuk.stojiljkovic999@gmail.com,
ORCID iD: https://orcid.org/0000-0002-4244-4342

[b] University of Belgrade, "Vinča" Institute of Nuclear Sciences - Institute of National Importance for the Republic of Serbia,
Belgrade, Republic of Serbia,
e-mail: nicola.fabiano@gmail.com, **corresponding author**,
ORCID iD: https://orcid.org/0000-0003-1645-2071

[c] TU Wien, Institute of Information Systems Engineering,
Vienna, Republic of Austria;
University of Belgrade, Faculty of Civil Engineering,
Belgrade, Republic of Serbia,
e-mail: vsesumcavic@grf.bg.ac.rs,
ORCID iD: https://orcid.org/0000-0002-0759-0686

DOI: 10.5937/vojtehg70-35148;https://doi.org/10.5937/vojtehg70-35148

FIELD: Mathematics
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: Some sums of the polylogarithmic function associated with harmonic numbers are established.

Methods: The approach is based on using the summation methods.

Results: This paper generalizes the results of the zeta function series associated with the harmonic numbers.

Conclusions: Various interesting series as the consequence of the generalization are obtained.

Key words: polylogarithmic function, series, harmonic numbers, integration.

Introduction and preliminaries

The polylogarithm is a function in mathematics which was investigated intensively by many mathematicians. Many of them used different definitions but the one we use is the standard modern definition. For more information about the polylogarithm as a function consult the following book

(Lewin, 1981). Questions about sums and their evaluations trace back to ancient times. Even the great Euler concerned himself with evaluating the $\zeta(2)$ known as the Basel problem, which was later generalized by him in view of finding a formula for even zeta values. More on various sums and evaluations can be found here (Hirschman, 2014; Knopp, 1990; Stojiljković, 2021; Davis, 2015). We will use the following notation throughout the paper. The first known definition is as follows.

DEFINITION 1. *The polylogarithm, see (Lewin, 1981), is defined by a power series in z, given by*

$$\mathrm{Li}_s(z) = \sum_{k=1}^{+\infty} \frac{z^k}{k^s}.$$

This definition is valid for the arbitrary complex order s and for all complex arguments z with $|z| < 1$. We will also need the definition given by

$$\mathrm{Li}_s(z) = \int_0^z \frac{\mathrm{Li}_{s-1}(z)}{z} dz.$$

Also, the special case we will use frequently is

$$\mathrm{Li}_2(z) = -\int_0^z \frac{\ln(1-z)}{z} dz.$$

For $z = 1$ we get the Riemann zeta function ζ which is also a function of the complex variable s. For more information see (Edwards, 1974; Fabiano, 2020).

$$\mathrm{Li}_s(1) = \zeta(s) = \sum_{k=1}^{+\infty} \frac{1}{k^s}, \Re(s) > 1$$

The second definition is as follows.

DEFINITION 2. *The harmonic numbers, see (Olaikhan, 2021), are defined as follows*

$$H_n := 1 + \frac{1}{2} + \frac{1}{3} + ... + \frac{1}{n}$$

for $n \geqslant 1$ and by definition $H_0 = 0$

The main results of this paper are the following.

Theorem 1. Let $\mathrm{Li}_s(z)$ denote the polylogarithmic function. Then the following equality holds for $|z| < 1$

$$\sum_{k=1}^{+\infty} H_k \left(\mathrm{Li}_s(z) - z - \cdots - \frac{z^k}{k^s} \right) = \int_0^1 \frac{\mathrm{Li}_{s-1}(z) - \mathrm{Li}_{s-1}(zm) + zm - z}{1-m} dm - \mathrm{Li}_{s-1}(z) + z.$$

Theorem 2. Let $\mathrm{Li}_s(z)$ denote the polylogarithmic function. Then the following equality holds for $|z| < 1$

$$\sum_{k=1}^{+\infty} k H_k \left(\mathrm{Li}_s(z) - z - \frac{z^2}{2^s} - \cdots - \frac{z^k}{k^s} \right) = \frac{1}{4} \left(\mathrm{Li}_{s-1}(z) - \mathrm{Li}_{s-2}(z) \right) + \frac{1}{2} \int_0^1 \frac{\mathrm{Li}_{s-2}(z) + \mathrm{Li}_{s-1}(zm) - \mathrm{Li}_{s-1}(z) - \mathrm{Li}_{s-2}(zm)}{1-m} dm.$$

Theorem 3. Let $\mathrm{Li}_s(z)$ denote the polylogarithmic function. Then the following equality holds for $|z| < 1$

$$\sum_{k=1}^{+\infty} H_k^2 \left(\mathrm{Li}_s(z) - z - \frac{z^2}{2^s} - \ldots - \frac{z^k}{k^s} \right) = \int_0^1 \frac{\int_0^1 \frac{\mathrm{Li}_{(s-1)}(z) - z - (\mathrm{Li}_{(s-1)}(zt) - zt)}{1-t} dt - \int_0^1 \frac{\mathrm{Li}_{(s-1)}(zm) - zm - (\mathrm{Li}_{(s-1)}(zmr) - zmr)}{1-r} dr}{(1-m)^2} dm - \int_0^1 \frac{\mathrm{Li}_{(s)}(z) - z - (\mathrm{Li}_{(s)}(zm) - zm)}{1-m} dm - 2 \left(\int_0^1 \frac{\mathrm{Li}_{s-1}(z) - \mathrm{Li}_{s-1}(zm) + zm - z}{1-m} dm - \mathrm{Li}_{s-1}(z) + z \right).$$

The corollaries of the results are given as follows.

COROLLARY 1. *The following equalities come from theorem 1.*

$$a) \sum_{k=1}^{+\infty} H_k \left(\mathrm{Li}_1(z) - z - \ldots - \frac{z^k}{k^1} \right) = \frac{z + \ln(1-z)}{z-1}, |z| < 1$$

Setting $z=\frac{1}{2}$ we get

$$b)\sum_{k=1}^{+\infty} H_k\left(\mathrm{Li}_1\left(\frac{1}{2}\right)-\frac{1}{2}-\ldots-\frac{(\frac{1}{2})^k}{k^1}\right)=\ln(4)-1.$$

We can also derive

$$c)\sum_{k=1}^{+\infty} H_k\left(\mathrm{Li}_2(z)-z-\ldots-\frac{z^k}{k^2}\right)=-\mathrm{Li}_2\left(\frac{z}{z-1}\right)-\mathrm{Li}_1(z).$$

By setting $z=\frac{1}{2}$ we get

$$d)\sum_{k=1}^{+\infty} H_k\left(\mathrm{Li}_2\left(\frac{1}{2}\right)-\frac{1}{2}-\ldots-\frac{(\frac{1}{2})^k}{k^2}\right)=\frac{\pi^2}{12}-\ln(2).$$

COROLLARY 2. *The following equalities come from Theorem 2.*

$$a)\sum_{k=1}^{+\infty} kH_k\left(\mathrm{Li}_2(z)-z-\frac{(z)^2}{2^2}-\cdots-\frac{(z)^k}{k^2}\right)=\frac{1}{2}\frac{\ln(1-z)}{z-1}+\frac{1}{2}\mathrm{Li}_2\left(\frac{z}{z-1}\right)+\frac{1}{4}\left(\mathrm{Li}_1(z)-\mathrm{Li}_0(z)\right).$$

By setting $z=\frac{1}{2}$ we get

$$b)\sum_{k=1}^{+\infty} kH_k\left(\mathrm{Li}_2\left(\frac{1}{2}\right)-\frac{1}{2}-\frac{(\frac{1}{2})^2}{2^2}-\cdots-\frac{(\frac{1}{2})^k}{k^2}\right)=\frac{5\ln(2)}{4}-\frac{1}{4}-\frac{\pi^2}{24}.$$

COROLLARY 3. *The following equalities come from Theorem 3.*

$$a)\sum_{k=1}^{+\infty} H_k^2\left(\mathrm{Li}_1(z)-z-\frac{z^2}{2^1}-\ldots-\frac{z^k}{k}\right)=-\frac{4z+\ln(1-z)\left(4+\ln(1-z)\right)-2z\,\mathrm{Li}_2(\frac{z}{z-1})}{2(z-1)}.$$

By setting $z=\frac{1}{2}$ we get

$$b)\sum_{k=1}^{+\infty} H_k^2\left(\mathrm{Li}_{(1)}\left(\frac{1}{2}\right)-\frac{1}{2}-\frac{(\frac{1}{2})^2}{2}-\ldots-\frac{(\frac{1}{2})^k}{k}\right)=2+\frac{\pi^2}{12}+\ln^2(2)-\ln(16).$$

Main results

We will need some lemmas in order to proceed further. The following lemma will be extensively used throughout the paper.

LEMMA 1. *The following equality holds for* $|z| < 1$.

$$\sum_{k=1}^{+\infty} \frac{z^{k+1}}{(k+1)^{s-1}} = \mathrm{Li}_{s-1}(z) - z$$

Proof. Follows from the definition of the polylogarithm. □

We will need the following in order to proceed further.
We will need in our analysis Abel's summation formula (Bonar & Koury, 2006, p.55),(Lewin, 1981, p.258), which states that if $(a_n)_{n\geqslant 1}$ and $(b_n)_{n\geqslant 1}$ are two sequences of real numbers and $A_n = \sum_{k=1}^{n} a_k$, then

$$\sum_{k=1}^{n} a_k b_k = A_n b_{n+1} + \sum_{k=1}^{n} A_k (b_k - b_{k+1})$$

We will also be using, in our calculations, the infinite version of the preceding formula

$$\sum_{k=1}^{+\infty} a_k b_k = \lim_{n\to+\infty} (A_n b_{n+1}) + \sum_{k=1}^{+\infty} A_k (b_k - b_{k+1}).$$

The second lemma will be given.

LEMMA 2. *The following identity holds:*

$$\sum_{k=1}^{n} H_k = (n+1)H_{n+1} - (n+1)$$

Proof. We will prove it using the Abel's summation (finite version). By choosing $a_k = 1, b_k = H_k$ we get

$$\sum_{k=1}^{n} H_k = nH_{n+1} + \sum_{k=1}^{n} k \cdot \left(-\frac{1}{k+1}\right) = nH_{n+1} - \sum_{k=1}^{n} \frac{k}{k+1} = nH_{n+1} - n$$
$$+ \sum_{k=1}^{n} \frac{1}{k+1} = nH_{n+1} - n + (H_{n+1} - 1) = (n+1)H_{n+1} - (n+1)$$

and the proof is done. □

The third lemma that we will need.

LEMMA 3. *The following equality holds.*

$$\sum_{k=1}^{n} kH_k = \frac{n(n+1)}{2} H_{n+1} - \frac{n(n+1)}{4}$$

Proof. We will prove it using the Abel's summation (finite version). By choosing $a_k = k, b_k = H_k$ we get

$$\sum_{k=1}^{n} kH_k = \frac{n(n+1)}{2} H_{n+1} + \sum_{k=1}^{n} \frac{k(k+1)}{2} \left(-\frac{1}{k+1}\right) =$$

$$= \frac{n(n+1)}{2} H_{n+1} - \sum_{k=1}^{n} \frac{k}{2} = \frac{n(n+1)}{2} H_{n+1} - \frac{n(n+1)}{4}$$

and the proof is complete. □

LEMMA 4. *The following equality holds for any q and for* $|z| < 1$

$$\lim_{k \to +\infty} k^q \left(\mathrm{Li}_s(z) - z - \cdots - \frac{z^{k+1}}{(k+1)^s} \right) = 0.$$

Proof. Let us observe the expression inside the brackets

$$\left(\mathrm{Li}_s(z) - z - \cdots - \frac{z^{k+1}}{(k+1)^s} \right) = \frac{z^{k+2}}{(k+2)^s} + \frac{z^{k+3}}{(k+3)^s} + \frac{z^{k+4}}{(k+4)^s} + \cdots$$

What we can realise is that every term is less than $\frac{z^k}{k^s}$; therefore, by

$$\frac{z^{k+2}}{(k+2)^s}+\frac{z^{k+3}}{(k+3)^s}+\frac{z^{k+4}}{(k+4)^s}+...\leq\frac{z^k}{k^s}+\frac{z^k}{k^s}+...$$

multiplying both sides by k^q and letting the limit go to infinity, we get

$$\lim_{k\to+\infty}k^q\left(\mathrm{Li}_s(z)-z-....-\frac{z^{k+1}}{(k+1)^s}\right)\leq\lim_{k\to+\infty}k^q\cdot\frac{kz^k}{k^s}=\lim_{k\to+\infty}\frac{z^k}{k^{s-q-1}}$$

and this will go to zero independently of $s-q-1$ because $|z|<1$ and z^k goes faster to zero than any power of the form k^{s-q-1}.

The proof is complete. □

We give our first generalization of the zeta function series.

LEMMA 5. *Let* $\mathrm{Li}_s(z)$ *denote the polylogarithmic function. Then the following equality holds for* $|z|<1$

$$\sum_{k=1}^{+\infty}\left(\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-...-\frac{z^k}{k^s}\right)=\mathrm{Li}_{s-1}(z)-\mathrm{Li}_s(z).$$

Proof. We apply the Abel's summation formula with $a_k=1$ and $b_k=\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-...-\frac{z^k}{k^s}$ from which we get

$$\sum_{k=1}^{+\infty}\left(\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-...-\frac{z^k}{k^s}\right)=$$

$$=\lim_{k\to+\infty}k\left(\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-...-\frac{z^k}{k^s}-\frac{z^{k+1}}{(k+1)^s}\right)+\sum_{k=1}^{+\infty}\frac{kz^{k+1}}{(k+1)^s}\ .$$

Since the first term goes to zero when $k\to+\infty$, Lemma 4 ($q=1$), we get

$$\sum_{k=1}^{+\infty}\left(\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-\ldots-\frac{z^k}{k^s}\right)=\sum_{k=1}^{+\infty}\frac{kz^{k+1}}{(k+1)^s}\ .$$

Adding and subtracting 1 in the numerator leaves us with two sums

$$\sum_{k=1}^{+\infty}\frac{z^{k+1}}{(k+1)^{s-1}}-\sum_{k=1}^{+\infty}\frac{z^{k+1}}{(k+1)^s}=\mathrm{Li}_{s-1}(z)-\mathrm{Li}_s(z)$$

because of Lemma 1. The proof is complete.

□

In the following we give a proof of Theorem 1.

THEOREM 1. *Let* $\mathrm{Li}_s(z)$ *denote the polylogarithmic function. Then the following equality holds for* $|z|<1$

$$\sum_{k=1}^{+\infty}H_k\left(\mathrm{Li}_s(z)-z-\cdots-\frac{z^k}{k^s}\right)=\int_0^1\frac{\mathrm{Li}_{s-1}(z)-\mathrm{Li}_{s-1}(zm)+zm-z}{1-m}dm$$
$$-\mathrm{Li}_{s-1}(z)+z.$$

Proof. By using Abel's theorem (infinite version) and choosing $a_k=H_k, b_k=\mathrm{Li}_s(z)-z-\cdots-\frac{z^k}{k^s}$ and Lemma 2 we get

$$\sum_{k=1}^{+\infty}H_k\left(\mathrm{Li}_s(z)-z-\ldots-\frac{z^k}{k^s}\right)=$$

$$=\lim_{k\to+\infty}((k+1)H_{k+1}-(k+1))\left(\mathrm{Li}_s(z)-z-\ldots-\frac{z^k}{k^s}-\frac{z^{k+1}}{(k+1)^s}\right)+$$

$$+\sum_{k=1}^{+\infty}\frac{((k+1)H_{k+1}-(k+1))z^{k+1}}{(k+1)^s}.$$

Since the first term goes to zero when $k\to+\infty$, Lemma 4 ($q=2$), the above equals to:

$$\sum_{k=1}^{+\infty}\frac{((k+1)H_{k+1}-(k+1))z^{k+1}}{(k+1)^s}=\sum_{k=1}^{+\infty}\frac{H_{k+1}z^{k+1}}{(k+1)^{s-1}}-\sum_{k=1}^{+\infty}\frac{z^{k+1}}{(k+1)^{s-1}}.$$

The second sum follows from Lemma 1. In the first sum we will rewrite the harmonic number as an integral and interchange the sum and the inte-

gral thanks to Fubini's theorem:

$$\sum_{k=1}^{+\infty} \frac{H_{k+1} z^{k+1}}{(k+1)^{s-1}} = \sum_{k=1}^{+\infty} \frac{z^{k+1}}{(k+1)^{s-1}} \int_0^1 \frac{1-m^{k+1}}{1-m} dm$$

$$= \int_0^1 \sum_{k=1}^{+\infty} \frac{z^{k+1}}{(k+1)^{s-1}} \frac{1-m^{k+1}}{1-m} dm \, .$$

By rewriting it as two sums, we get

$$\int_0^1 \frac{\sum_{k=1}^{+\infty} \frac{z^{k+1}}{(k+1)^{s-1}} - \sum_{k=1}^{+\infty} \frac{(mz)^{k+1}}{(k+1)^{s-1}}}{1-m} dm \, .$$

Using the results from the Lemma 1 leaves us with

$$= \int_0^1 \frac{\mathrm{Li}_{s-1}(z) - z - (\mathrm{Li}_{s-1}(zm) - zm)}{1-m} dm.$$

Which, when substituted above, gives us:

$$\sum_{k=1}^{+\infty} H_k \left(\mathrm{Li}_s(z) - z - \ldots - \frac{z^k}{k^s} \right) = \int_0^1 \frac{\mathrm{Li}_{s-1}(z) - \mathrm{Li}_{s-1}(zm) + zm - z}{1-m} dm$$

$$- \mathrm{Li}_{s-1}(z) + z.$$

□

Now we prove Corollary 1, part **a)**.

When $s = 1$ it can be shown, after a long and tedious calculation, that the following holds

$$\sum_{k=1}^{+\infty} H_k \left(\mathrm{Li}_1(z) - z - \ldots - \frac{z^k}{k^1} \right) = \frac{z + \ln(1-z)}{z-1}, |z| < 1.$$

By setting $z = \frac{1}{2}$ we get **b)**

$$\sum_{k=1}^{+\infty} H_k \left(\mathrm{Li}_1\left(\frac{1}{2}\right) - \frac{1}{2} - \ldots - \frac{(\frac{1}{2})^k}{k^1} \right) = \ln(4) - 1.$$

When $s = 2$ it can be shown, similarly to the case $s = 1$, that **c)** part holds

$$\sum_{k=1}^{+\infty} H_k \left(\mathrm{Li}_2(z) - z - ... - \frac{z^k}{k^2} \right) = -\mathrm{Li}_2\left(\frac{z}{z-1} \right) - \mathrm{Li}_1(z).$$

By setting $z = \frac{1}{2}$ we arrive at **d)**

$$\sum_{k=1}^{+\infty} H_k \left(\mathrm{Li}_2\left(\frac{1}{2}\right) - \frac{1}{2} - ... - \frac{(\frac{1}{2})^k}{k^2} \right) = \frac{\pi^2}{12} - \ln(2).$$

In the following we give proof of Theorem 2.

THEOREM 2. *Let* $\mathrm{Li}_s(z)$ *denote the polylogarithmic function. Then the following equality holds for* $|z| < 1$

$$\sum_{k=1}^{+\infty} kH_k \left(\mathrm{Li}_s(z) - z - \frac{z^2}{2^s} - ... - \frac{z^k}{k^s} \right) = \frac{1}{4} \left(\mathrm{Li}_{s-1}(z) - \mathrm{Li}_{s-2}(z) \right) + \frac{1}{2} \int_0^1 \frac{\mathrm{Li}_{s-2}(z) + \mathrm{Li}_{s-1}(zm) - \mathrm{Li}_{s-1}(z) - \mathrm{Li}_{s-2}(zm)}{1-m} dm.$$

Proof. Using the Abel's summation with $a_k = kH_k$ and $b_k = \mathrm{Li}_s(z) - \frac{z}{1^s} - ... - \frac{z^k}{k^s}$ and Lemma 3 for the a_k part gives

$$\sum_{k=1}^{+\infty} kH_k \left(\mathrm{Li}_s(z) - z - \frac{z^2}{2^s} - ... - \frac{z^k}{k^s} \right) = \lim_{k \to +\infty} \left(\frac{k(k+1)H_{k+1}}{2} - \frac{k(k+1)}{4} \right) \cdot \left(\mathrm{Li}_s(z) - z - \frac{z^2}{2^s} - ... - \frac{z^k}{k^s} - \frac{z^{k+1}}{(k+1)^s} \right) + \sum_{k=1}^{+\infty} \left(\frac{k(k+1)H_{k+1}}{2} - \frac{k(k+1)}{4} \right) \cdot \frac{z^{k+1}}{(k+1)^s}.$$

The expression in the brackets goes to zero by Lemma 4, so we are left with:

$$\frac{1}{2} \sum_{k=1}^{+\infty} \frac{kH_{k+1} z^{k+1}}{(k+1)^{s-1}} - \frac{1}{4} \sum_{k=1}^{+\infty} \frac{kz^{k+1}}{(k+1)^{s-1}}.$$

We will use Lemma 1:

$$\sum_{k=1}^{+\infty} \frac{kz^{k+1}}{(k+1)^s} = \mathrm{Li}_{s-1}(z) - \mathrm{Li}_s(z) \ .$$

As we can see, the second sum is the expression above with s shifted by -1 and multiplied by $\frac{1}{4}$. For the first sum, we will rewrite the harmonic number into its integral form.

$$\frac{1}{2}\sum_{k=1}^{+\infty}\frac{kH_{k+1}z^{k+1}}{(k+1)^{s-1}}=\frac{1}{2}\sum_{k=1}^{+\infty}\frac{kz^{k+1}}{(k+1)^{s-1}}\int_0^1\frac{1-m^{k+1}}{1-m}dm=$$
$$\int_0^1\frac{1}{2}\sum_{k=1}^{+\infty}\frac{kz^{k+1}}{(k+1)^{s-1}}\frac{1-m^{k+1}}{1-m}dm=$$
$$\frac{1}{2}\int_0^1\frac{\sum_{k=1}^{+\infty}\frac{kz^{k+1}}{(k+1)^{s-1}}-\sum_{k=1}^{+\infty}\frac{k(zm)^{k+1}}{(k+1)^{s-1}}}{1-m}dm\,.$$

Both sums are of the form given above. Therefore, we get

$$\frac{1}{2}\int_0^1\frac{\mathrm{Li}_{s-2}(z)-\mathrm{Li}_{s-1}(z)-(\mathrm{Li}_{s-2}(zm)-\mathrm{Li}_{s-1}(zm))}{1-m}dm\,.$$

By incorporating this into the original equality, we get

$$\sum_{k=1}^{+\infty}kH_k\left(\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-\ldots-\frac{z^k}{k^s}\right)=\frac{1}{4}\left(\mathrm{Li}_{s-1}(z)-\mathrm{Li}_{s-2}(z)\right)+$$
$$\frac{1}{2}\int_0^1\frac{\mathrm{Li}_{s-2}(z)+\mathrm{Li}_{s-1}(zm)-\mathrm{Li}_{s-1}(z)-\mathrm{Li}_{s-2}(zm)}{1-m}dm.$$

□

By setting $s=2$ it can be shown that Corollary 2 part **a)** holds

$$\sum_{k=1}^{+\infty}kH_k\left(\mathrm{Li}_2(z)-z-\frac{(z)^2}{2^2}-\ldots-\frac{(z)^k}{k^2}\right)=\frac{1}{2}\frac{\ln(1-z)}{z-1}+\frac{1}{2}\mathrm{Li}_2\left(\frac{z}{z-1}\right)+$$
$$\frac{1}{4}\left(\mathrm{Li}_1(z)-\mathrm{Li}_0(z)\right).$$

By setting $z=\frac{1}{2}$ we arrive at part **b)**

$$\sum_{k=1}^{+\infty}kH_k\left(\mathrm{Li}_2\left(\frac{1}{2}\right)-\frac{1}{2}-\frac{(\frac{1}{2})^2}{2^2}-\ldots-\frac{(\frac{1}{2})^k}{k^2}\right)=\frac{1}{2}\left(-\frac{\pi^2}{12}+\ln(4)\right)+$$

$$\frac{1}{4}\left(\ln(2)-1\right).$$

Our significant result in this paper is given in the following theorem. The next theorem will use all the previous results.

THEOREM 3. *Let* $\mathrm{Li}_s(z)$ *denote the polylogarithmic function. Then the following equality holds for* $|z|<1$

$$\sum_{k=1}^{+\infty} H_k^2\left(\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-...-\frac{z^k}{k^s}\right)=$$
$$\int_0^1 \frac{\int_0^1 \frac{\mathrm{Li}_{(s-1)}(z)-z-(\mathrm{Li}_{(s-1)}(zt)-zt)}{1-t}dt-\int_0^1 \frac{\mathrm{Li}_{(s-1)}(zm)-zm-(\mathrm{Li}_{(s-1)}(zmr)-zmr)}{1-r}dr}{1-m}dm$$
$$-\int_0^1 \frac{\mathrm{Li}_{(s)}(z)-z-(\mathrm{Li}_{(s)}(zm)-zm)}{1-m}dm-$$
$$2\left(\int_0^1 \frac{\mathrm{Li}_{s-1}(z)-\mathrm{Li}_{s-1}(zm)+zm-z}{1-m}dm-\mathrm{Li}_{s-1}(z)+z\right).$$

Proof. We will use Abel's summation method, choosing $a_k=H_k, b_k=H_k\left(\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-...-\frac{z^k}{k^s}\right)$ with Lemma 2, we will use the following notation to minimize the clutter in the formulas, let us call $S_k=\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-...-\frac{z^k}{k^s}$. By evaluating b_k-b_{k+1} we get

$$b_k-b_{k+1}=\frac{H_k z^{k+1}}{(k+1)^s}-\frac{S_k}{(k+1)}+\frac{z^{k+1}}{(k+1)^{s+1}}.$$

By using Abel's summation we get

$$\lim_{k\to+\infty}\left((k+1)H_{k+1}-(k+1)\right)H_{k+1}S_{k+1}+$$

$$+\sum_{k=1}^{+\infty}\left((k+1)H_{k+1}-(k+1)\right)\left(\frac{H_k z^{k+1}}{(k+1)^s}-\frac{S_k}{(k+1)}+\frac{z^{k+1}}{(k+1)^{s+1}}\right).$$

The expression in the limit goes to zero by Lemma 4. We are left with the sum

$$\sum_{k=1}^{+\infty}\frac{H_{k+1}H_k z^{k+1}}{(k+1)^{s-1}}-\sum_{k=1}^{+\infty}S_k H_{k+1}+\sum_{k=1}^{+\infty}\frac{z^{k+1}H_{k+1}}{(k+1)^s}-\sum_{k=1}^{+\infty}\frac{H_k z^{k+1}}{(k+1)^{s-1}}+$$

$$\sum_{k=1}^{+\infty} S_k - \sum_{k=1}^{+\infty} \frac{z^{k+1}}{(k+1)^s}.$$

We know the third term from the proof of Theorem 1, the fifth term from Lemma 5 and the sixth term from Lemma 1. Let us focus on the second one, $\sum_{k=1}^{+\infty} H_{k+1}S_k$. This is a separate problem we must deal with. So let us write

$$\sum_{k=1}^{+\infty} H_{k+1}S_k = \sum_{k=1}^{+\infty} \left(H_k + \frac{1}{k+1}\right) S_k = \sum_{k=1}^{+\infty} H_k S_k + \sum_{k=1}^{+\infty} \frac{S_k}{k+1}.$$

The first term is known from Theorem 1, but the second one is not, so we will use again Abel's summation method choosing $a_k = \frac{1}{k+1}, b_k = S_k$. We get

$$\lim_{k\to+\infty} (H_{k+1}-1)S_{k+1} + \sum_{k=1}^{+\infty} (H_{k+1}-1)\frac{z^{k+1}}{(k+1)^s} = \sum_{k=1}^{+\infty} \frac{z^{k+1}H_{k+1}}{(k+1)^s} - \sum_{k=1}^{+\infty} \frac{z^{k+1}}{(k+1)^s}$$

The first sum is from the proof of Theorem 1 while the second one is from Lemma 1; therefore, the original second sum is done. Let us deal with the fourth sum:

$$\sum_{k=1}^{+\infty} \frac{H_k z^{k+1}}{(k+1)^{s-1}} = \sum_{k=1}^{+\infty} \left(H_k + \frac{1}{k+1} - \frac{1}{k+1}\right) \frac{z^{k+1}}{(k+1)^{s-1}} = \sum_{k=1}^{+\infty} \frac{H_{k+1}z^{k+1}}{(k+1)^{s-1}} - \sum_{k=1}^{+\infty} \frac{z^{k+1}}{(k+1)^s}.$$

The first sum is from the proof of Theorem 1 while the second one is from Lemma 1. Therefore, the fourth sum is done. Let us focus on the first one.

$$\sum_{k=1}^{+\infty} \frac{H_{k+1}H_k z^{k+1}}{(k+1)^{s-1}} = \sum_{k=1}^{+\infty} \frac{H_{k+1}\left(H_k + \frac{1}{k+1} - \frac{1}{k+1}\right)}{(k+1)^{s-1}} = \sum_{k=1}^{+\infty} \frac{H_{k+1}^2 z^{k+1}}{(k+1)^{s-1}} - \sum_{k=1}^{+\infty} \frac{z^{k+1}H_{k+1}}{(k+1)^s}.$$

The second one is from the proof of Theorem 1, but we need to dig further for the first one

$$\sum_{k=1}^{+\infty}\frac{H_{k+1}^2 z^{k+1}}{(k+1)^{s-1}}=\sum_{k=1}^{+\infty}\frac{H_{k+1}z^{k+1}}{(k+1)^{s-1}}\int_0^1\frac{1-m^{k+1}}{1-m}dm=$$
$$\int_0^1\frac{\sum_{k=1}^{+\infty}\frac{H_{k+1}z^{k+1}}{(k+1)^{s-1}}-\sum_{k=1}^{+\infty}\frac{H_{k+1}(mz)^{k+1}}{(k+1)^{s-1}}}{1-m}dm.$$

The second term is the same as in Theorem 1 when taking z as zm; therefore, the result follows.

$$\sum_{k=1}^{+\infty}\frac{H_{k+1}(zm)^{k+1}}{(k+1)^{s-1}}=\int_0^1\frac{\mathrm{Li}_{s-1}(zm)-zm-(\mathrm{Li}_{s-1}(zmr)-zmr)}{1-r}dr$$

While the first one we have directly from the proof of Theorem 1

$$\sum_{k=1}^{+\infty}\frac{H_{k+1}z^{k+1}}{(k+1)^{s-1}}=\int_0^1\frac{\mathrm{Li}_{(s-1)}(z)-z-(\mathrm{Li}_{(s-1)}(zt)-zt)}{1-t}dt.$$

Therefore, by putting all together, we obtain

$$\sum_{k=1}^{+\infty}\frac{H_{k+1}H_k z^{k+1}}{(k+1)^{s-1}}-\sum_{k=1}^{+\infty}S_k H_{k+1}+\sum_{k=1}^{+\infty}\frac{z^{k+1}H_{k+1}}{(k+1)^s}-\sum_{k=1}^{+\infty}\frac{H_k z^{k+1}}{(k+1)^{s-1}}+$$
$$\sum_{k=1}^{+\infty}S_k-\sum_{k=1}^{+\infty}\frac{z^{k+1}}{(k+1)^s}=\sum_{k=1}^{+\infty}\frac{H_{k+1}^2 z^{k+1}}{(k+1)^{s-1}}-\sum_{k=1}^{+\infty}\frac{z^{k+1}H_{k+1}}{(k+1)^s}-\left(\sum_{k=1}^{+\infty}H_k S_k+\right.$$
$$\left.\sum_{k=1}^{+\infty}\frac{z^{k+1}H_{k+1}}{(k+1)^s}-\sum_{k=1}^{+\infty}\frac{z^{k+1}}{(k+1)^s}\right)+\sum_{k=1}^{+\infty}\frac{z^{k+1}H_{k+1}}{(k+1)^s}-\left(\sum_{k=1}^{+\infty}\frac{H_{k+1}z^{k+1}}{(k+1)^{s-1}}-\right.$$
$$\left.\sum_{k=1}^{+\infty}\frac{z^{k+1}}{(k+1)^s}\right)+\sum_{k=1}^{+\infty}S_k-\sum_{k=1}^{+\infty}\frac{z^{k+1}}{(k+1)^s}.$$

We can see that four of the terms will cancel themselves; then we plug the polylogarithm expressions we have got and establish the equality.

$$\sum_{k=1}^{+\infty}H_k^2\left(\mathrm{Li}_s(z)-z-\frac{z^2}{2^s}-\ldots-\frac{z^k}{k^s}\right)=$$

$$\int_0^1 \frac{\int_0^1 \frac{\mathrm{Li}_{(s-1)}(z)-z-(\mathrm{Li}_{(s-1)}(zt)-zt)}{1-t}dt - \int_0^1 \frac{\mathrm{Li}_{(s-1)}(zm)-zm-(\mathrm{Li}_{(s-1)}(zmr)-zmr)}{1-r}dr}{1-m}dm$$
$$- \int_0^1 \frac{\mathrm{Li}_{(s)}(z)-z-(\mathrm{Li}_{(s)}(zm)-zm)}{1-m}dm -$$
$$2\left(\int_0^1 \frac{\mathrm{Li}_{s-1}(z)-\mathrm{Li}_{s-1}(zm)+zm-z}{1-m}dm - \mathrm{Li}_{s-1}(z)+z\right).$$

And the proof is done. □

By setting s=1 in theorem 3 we arrive at Corollary 3 part **a)**

$$\sum_{k=1}^{+\infty} H_k^2 \left(\mathrm{Li}_1(z) - z - \frac{z^2}{2^1} - \ldots - \frac{z^k}{k}\right) =$$
$$-\frac{4z+\ln(1-z)\,(4+\ln(1-z))-2z\,\mathrm{Li}_2(\frac{z}{z-1})}{2(z-1)}.$$

By setting $z=\frac{1}{2}$ we arrive at part **b)** of Corollary 3

$$\sum_{k=1}^{+\infty} H_k^2 \left(\mathrm{Li}_{(1)}\left(\frac{1}{2}\right) - \frac{1}{2} - \frac{(\frac{1}{2})^2}{2} - \ldots - \frac{(\frac{1}{2})^k}{k}\right) = 2 + \frac{\pi^2}{12} + \ln^2(2) - \ln(16).$$

Some examples of series

The usage of the previously derived theorems will be displayed in the following examples. Equipped with the series in a closed form we have derived, we can get many series via incorporating the values from the domain which is $|z|<1$. By letting $z=\frac{\sqrt{5}-1}{2}$ in Corollary 1 part c), Corollary 2 part a) and Corollary 3 part a) we get, respectively

$$\sum_{k=1}^{+\infty} H_k \left(\mathrm{Li}_2\left(\frac{\sqrt{5}-1}{2}\right) - \frac{\sqrt{5}-1}{2} - \ldots - \frac{(\frac{\sqrt{5}-1}{2})^k}{k^2}\right) =$$

$$= \frac{\pi^2}{10} + \ln^2\left(\frac{1}{2}+\frac{\sqrt{5}}{2}\right) + \ln\left(\frac{1}{2}(3-\sqrt{5})\right)$$

$$\sum_{k=1}^{+\infty} kH_k \left(\mathrm{Li}_2\left(\frac{\sqrt{5}-1}{2}\right) - \frac{\sqrt{5}-1}{2} - \frac{(\frac{\sqrt{5}-1}{2})^2}{2^2} - \ldots - \frac{(\frac{\sqrt{5}-1}{2})^k}{k^2}\right) =$$

$$= -\frac{1-\sqrt{5}+(\sqrt{5}-7)\ln\left(\frac{1}{2}(3-\sqrt{5})\right)+2(\sqrt{5}-3)\,\mathrm{csch}^{-1}(2)^2}{4(\sqrt{5}-3)} - \frac{\pi^2}{20}$$

$$\sum_{k=1}^{+\infty} H_k^2 \left(\mathrm{Li}_1\left(\frac{\sqrt{5}-1}{2}\right) - \frac{\sqrt{5}-1}{2} - \frac{(\frac{\sqrt{5}-1}{2})^2}{2^1} - \ldots - \frac{(\frac{\sqrt{5}-1}{2})^k}{k}\right) =$$

$$= -\frac{1}{10(\sqrt{5}-3)}\left((\sqrt{5}-1)\pi^2 - 20 + 20\sqrt{5}\right) +$$

$$+\frac{-1}{\sqrt{5}-3}\left(\ln\left(\frac{1}{2}(47-21\sqrt{5})\right) + \cosh^{-1}\left(\frac{3}{2}\right)^2 + (\sqrt{5}-1)\,\mathrm{csch}^{-1}(2)^2\right)$$

More interesting sums can be obtained incorporating in the value $z = \frac{3-\sqrt{5}}{2}$.

By setting $z = \frac{3-\sqrt{5}}{2}$ in Corollary 1 part c), Corollary 2 part a) and Corollary 3 part a), we get, respectively

$$\sum_{k=1}^{+\infty} H_k \left(\mathrm{Li}_2\left(\frac{3-\sqrt{5}}{2}\right) - \frac{3-\sqrt{5}}{2} - \ldots - \frac{(\frac{3-\sqrt{5}}{2})^k}{k^2}\right) =$$

$$= \frac{\pi^2}{15} - \frac{1}{2}\,\mathrm{csch}^{-1}(2)\left(2 + \mathrm{csch}^{-1}(2)\right)$$

$$\sum_{k=1}^{+\infty} kH_k \left(\mathrm{Li}_2\left(\frac{3-\sqrt{5}}{2}\right) - \frac{3-\sqrt{5}}{2} - \ldots - \frac{(\frac{3-\sqrt{5}}{2})^k}{k^2}\right) =$$

$$\frac{1}{16}\left(2 - 2\sqrt{5} + (1+\sqrt{5})\sinh^{-1}(2) + \mathrm{csch}^{-1}(2)(5+\sqrt{5}+4\,\mathrm{csch}^{-1}(2))\right) - \frac{\pi^2}{30}$$

$$\sum_{k=1}^{+\infty} H_k^2 \left(\mathrm{Li}_2\left(\frac{3-\sqrt{5}}{2}\right) - \frac{3-\sqrt{5}}{2} - \ldots - \frac{(\frac{3-\sqrt{5}}{2})^k}{k^2}\right) =$$

$$= \frac{1}{30}\left((\sqrt{5}-1)\pi^2 + 15(2(\sqrt{5}-1) - 2(1+\sqrt{5})\,\mathrm{csch}^{-1}(2) + \mathrm{csch}^{-1}(2)^2)\right).$$

The numerical values of Li_2 at the points $z = \frac{\sqrt{5}-1}{2}, -\frac{\sqrt{5}-1}{2}, -\frac{1+\sqrt{5}}{2}$ can be found here (Lewin, 1981). Many more series can be obtained by substituting different values.

Conclusions

1. To assure the accuracy of the results, we verified all the numerical series identities through Wolfram Alpha.

2. Further questions can be asked regarding the sums with harmonic numbers of an arbitrary order as to, whether it is possible to find more of them of the form $H_{\frac{n}{k}}$ for some fixed k.

3. In this paper, we generalized the results given in (Furdui, 2016) as the polylogarithm is a generalization of the zeta function since $\mathrm{Li}_s(1) = \zeta(s)$. We can obtain many more series by varying the two parameters z and s.

References

Bonar, D.D. and Khoury, M.J. 2006. *Real Infinite Series*. Washington D.C., American Mathematical Society: MAA Press. ISBN: 978-1-4704-4782-3.

Davis, H.T. 2015. *The Summation of Series (Dover Books on Mathematics)*. Mineola, New York: Dover Publications. ISBN-13: 978-0486789682.

Edwards, M.H. 1974. *Riemann's Zeta Function*. Mineola, New York: Dover Publications. ISBN-13: 978-0486417400.

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.

Furdui, O. 2016. Harmonic series with polygamma functions. *Journal of Classical Analysis*, 8(2), pp.123-130. Available at: https://doi.org/10.7153/jca-08-11.

Hirschman, I.I. 2014. *Infinite series (Dover Books on Mathematics)*. Mineola, New York: Dover Publications. ISBN-13: 978-0-486-78975-0.

Knopp, K. 1990. *Theory and Applications of Infinite Series*. Mineola, New York: Dover Publications. ISBN-13: 978-0-486-66165-2.

Lewin, L. 1981. *Polylogarithms and associated functions*. Elsevier Science Ltd. ISBN-13: 978-0444005502.

Olaikhan, A.S. 2021. *An Introduction To The Harmonic Series And Logarithmic Integrals: For High School Students Up To Researcher*. Ali Shadhar Olaikhan (private edition). ISBN-13: 978-1-7367360-0-5.

Stojiljković, V. 2021. Some Series Associated with Central Binomial Coefficients and Harmonic Numbers. *Octogon Mathematical Magazine*, 29(2).

ГАРМОНИЧЕСКИЙ РЯД С ПОЛИЛОГАРИФМИЧЕСКИМИ ФУНКЦИЯМИ

Вук Стоилькович[а], *Никола* Фабиано[б], *Весна* Шешум Чавич[в]

[а] Нови-Садский университет, факультет естественных наук, г. Нови-Сад, Республика Сербия

[б] Белградский университет, Институт ядерных исследований «Винча» − Институт государственного значения для Республики Сербия, г. Белград, Республика Сербия, **корреспондент**

[в] TU Wien, Институт инженерии информационных систем, г. Вена, Республика Австрия;
Белградский университет, инженерно-строительный факультет, г. Белград, Республика Сербия

РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА:
27.23.25 Специальные функции,
27.25.15 Дескриптивная теория функций

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Устанавлены некоторые суммы поли- логарифмической функции, связанные с гармоническими числами.

Методы: Подход основан на использовании методов суммирования.

Результаты: В данной статье обобщены результаты ряда дзета-функций, связанных с гармоническими числами.

Выводы: В следствие обобщения получены различные интересные ряды.

Ключевые слова: полилогарифмическая функция, ряды, гармонические числа, интегрирование.

ХАРМОНИЧНИ НИЗ СА ПОЛИЛОГАРИТАМСКИМ ФУНКЦИЈАМА

Вук Стојиљковић[а], *Никола* Фабиано[б], *Весна* Шешум Чавић[в]

[а] Универзитет у Новом Саду, Природно-математички факултет, Нови Сад, Република Србија

[б] Универзитет у Београду, Институт за нуклеарне науке "Винча"- Институт од националног значаја за Републику Србију, Београд, Република Србија, **аутор за преписку**

[в] Технички универзитет у Бечу, Институт за инжењерство информационих система, Беч, Република Аустрија; Универзитет у Београду, Грађевински факултет, Београд, Република Србија

ОБЛАСТ: математика
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Установљене су неке суме полилогаритамске функције повезане са хармонијским бројевима.

Методе: Приступ се заснива на коришћењу метода сумирања.

Резултати: Генерализовани су резултати низа зета - функција повезаних са хармонијским бројевима.

Закључак: Добијени су различити занимљиви низови као последица генерализације.

Кључне речи: полилогаритамска функција, серија, хармонијски бројеви, интеграција.

Paper received on / Дата получения работы / Датум пријема чланка: 30.11.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 03.01.2022.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 04.01.2022.

PICTURE-WISE JUST NOTICEABLE DIFFERENCE PREDICTION MODEL FOR JPEG IMAGE QUALITY ASSESSMENT

Boban P. Bondžulić[a], *Boban* Z. Pavlović[b], *Nenad* M. Stojanović[c], *Vladimir* S. Petrović[d]

[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 Telecommunications and Informatics, Belgrade, Republic of Serbia, e-mail: bobanpav@yahoo.com, **corresponding author**, ORCID iD: https://orcid.org/0000-0002-5476-7894

[c] University of Defence in Belgrade, Military Academy, Department of Telecommunications and Informatics, Belgrade, Republic of Serbia, e-mail: nivzvk@hotmail.com, ORCID iD: https://orcid.org/0000-0001-9328-5348

[d] University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Republic of Serbia, e-mail: vpetrovic@visaris.com, ORCID iD: https://orcid.org/0000-0002-8299-8999

DOI: 10.5937/vojtehg70-34739; https://doi.org/10.5937/vojtehg70-34739

FIELD: Telecommunications
ARTICLE TYPE: Original scientific paper

Summary:

Introduction/purpose: The paper presents interesting research related to the performance analysis of the picture-wise just noticeable difference (JND) prediction model and its application in the quality assessment of images with JPEG compression.

Methods: The performance analysis of the JND model was conducted in an indirect way by using the publicly available results of subject-rated image datasets with the separation of images into two classes (above and below the threshold of visible differences). In the performance analysis of the JND prediction model and image quality assessment, five image datasets were used, four of which come from the visible wavelength range, and one dataset is intended for remote sensing and surveillance with images from the infrared part of the electromagnetic spectrum.

ACKNOWLEDGMENT:
This research has been a part of Project No. VA-TT/3/20-22 supported by the Ministry of Defence, Republic of Serbia.

Results: The paper shows that using a picture-wise JND model, subjective image quality assessment scores can be estimated with better accuracy, leading to significant performance improvements of the traditional peak signal-to-noise ratio (PSNR). The gain achieved by introducing the picture-wise JND model in the objective assessment depends on the chosen dataset and the results of the initial simple to compute PSNR measure, and it was obtained on all five datasets. The mean linear correlation coefficient (for five datasets) between subjective and PSNR objective quality estimates increased from 74% (traditional PSNR) to 90% (picture-wise JND PSNR).

Conclusion: *Further improvement of the JND-based objective measure can be obtained by improving the picture-wise model of JND prediction.*

Key words: just noticeable difference, JPEG compression, peak signal-to-noise ratio, subjective and objective image quality assessment.

Introduction

With the rapid development of systems for digital processing, transmission and display of images and videos, there has been a growing interest in efficient image/video compression techniques (Lu et al, 2021). Among the techniques intended for image compression, the JPEG technique (Wallace, 1992), (Pennebaker & Mitchell, 1993) has been the most widely accepted for more than 25 years. The original JPEG development team members emphasize that the longevity of this technique is a consequence of well-defined mandatory conditions that it had to meet and fundamental components such as fast discrete cosine transform, psychovisual quantization, modeling, encoding, a royalty-free baseline, progressive modes, lossless compression support and real-time implementation (Hudson et al, 2017), (Hudson et al, 2018). The JPEG technique still meets the average user demand, so it is to be expected that it will be present in the coming decades.

Image compression techniques, along with the elimination of coding and spatial redundancy, use some of the characteristics of the human visual system (HVS), i.e. use visual redundancy. One of the characteristics is related to the just noticeable difference (JND) threshold. JND, as a perceptual threshold in image processing, is used in perceptual image compression (Tian et al, 2020), (Wang et al, 2019), and can also be used in objective image quality assessment (Toprak & Yalman, 2017), (Seo et al, 2021). The first and most significant JND threshold/point refers to the transition between a pristine and an image with visible distortions, or rather the transition from perceptually lossless

to perceptually lossy encoding (Huang et al, 2018). Research on JND has intensified in recent years thanks to publicly available image and video datasets with the results of subjective tests, among which there are three JND-based image datasets with JPEG compression (Jin et al, 2016), (Liu et al, 2018), (Ahar et al, 2018). These three datasets are intended for different purposes – compression of natural images (Jin et al, 2016), compression of panoramic images (Liu et al, 2018) and compression of high dynamic range images (Ahar et al, 2018). JND-based subjective quality analyses also have been conducted on JPEG 2000, H.265 and VVC compressed images, and on H.264 and H.265 compressed videos (Bondžulić et al, 2021).

The MCL-JCI dataset described in (Jin et al, 2016), as a dataset of natural scene images, contains information on the JND points of JPEG compressed images and was used to predict JND points in (Fan et al, 2019), (Lin et al, 2020), (Liu et al, 2020), (Bondžulić et al, 2021). The mean absolute error (MAE) of the PSNR between the predicted and ground truth JND distributions was used as a prediction accuracy measure. The deep learning approaches (Fan et al, 2019), (Lin et al, 2020), (Liu et al, 2020) yielded the MAE for the first JND point of 0.69 dB, 0.58 dB and 0.79 dB, respectively. Recent research published in (Bondžulić et al, 2021) has shown that based on only one feature derived from a source non-compressed image (mean gradient magnitude, MGM), the PSNR of the first JND point of an image with JPEG compression can be reliably predicted (linear correlation coefficient between PSNR of the predicted and ground truth first JND points is greater than 92%, while the MAE between them is 1.21 dB). The proposed approach does not require complex vision or masking models and determines the optimal JPEG quality factor through a simple rate-distortion function using the computationally efficient PSNR metric for objective quality assessment. The high degree of correlation can be explained by a good prediction of image complexity using MGM, which is essential in determining the degree of compression and bandwidth allocation (Yu & Winkler, 2013).

The research in this paper aims to further confirm the success of the prediction of the first JND points for a given image using a simple and fast approach (Bondžulić et al, 2021) and to show that the information of position of the first JND points can be used to reliably evaluate quality of images with JPEG compression. Prediction success and reliable evaluation were confirmed on five subject-rated image datasets containing images with JPEG compression.

Prediction of the first JND point for JPEG compressed images

The quality factor (QF), whose values range from 0 to 100, has been used to control the quality of JPEG compressed images. Higher QF values correspond to better quality images. Although one can choose a QF from 0 to 100, with an increment equal to one, recent research has shown that observers can distinguish a finite number of image quality levels (four to eight), and that the relationship between perceptual distortions and a bit-rate/distortion level is not a continuous but a step function (Jin et al, 2016). The steps of this function represent the JND points. The first among them, and at the same time the most important JND point, refers to the maximum difference between the original and the test image that the HVS will not notice (Li et al, 2020), (Bondžulić et al, 2017). This transition point between the original image and the images with visible degradations also represents the transition from perceptually lossless to perceptually lossy encoding. The second JND point is obtained by detecting noticeable differences from the first JND point (anchor), i.e. lower JND points are used as anchors to determine higher JND points.

Figure 1 shows the original uncompressed image from the MCL-JCI dataset (Jin et al, 2016), its stepwise distribution of JND points and the regions of the original image and images corresponding to JND points. The results of subjective tests were given through the stair quality function (SQF), which represents the normalized cumulative sum of the JND function, and was obtained by analysing and post-processing raw JND data. The height of the SQF function for a boundary point with QF=100 is equal to one and defines the maximum possible quality. The first drop in quality corresponds to the first JND point (JND #1), and its height corresponds to subjective quality. This point corresponds to the image with QF=35, and its subjective quality is SQF=0.92. The position of the first JND point depends on the image content and for 50 source images from the MCL-JCI dataset these positions were obtained for a wide range of QF values, from 25 to 70 (Jin et al, 2016).

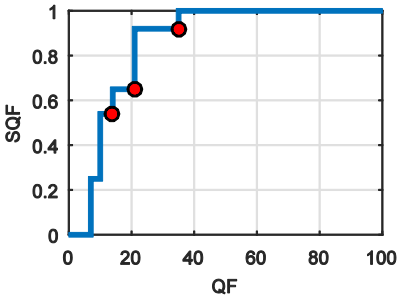
The regions in Figure 1 show visible differences between the images corresponding to the higher JND points (JND #2 and JND #3) and the region of the original image.

Prediction of the first JND point for JPEG compressed images can be achieved in the PSNR, QF, and bits per pixel (bpp) domains, but researchers suggested using the PSNR domain to predict the first JND point (Liu et al, 2020), (Bondžulić et al, 2021).

The procedure for determining the estimation of the ground truth PSNR value (PSNR JND #1) proposed in (Bondžulić et al, 2021) is carried out in several steps. In the first step, if it is a color image, the conversion from the RGB color format to a grayscale image is performed (Gonzalez & Woods, 2018):

$$f(n,m) = 0.299R(n,m) + 0.587G(n,m) + 0.114B(n,m). \quad (1)$$

(a)



(b)

(c) original

(d) JND #1 (QF=35, SQF=0.92)

(e) JND #2 (QF=21, SQF=0.65)

(f) JND #3 (QF=14, SQF=0.54)

Figure 1 – (a) (b) original image rich in detail and its SQF function, (c) (d) (e) and (f) regions of the original image and compressed images corresponding to the JND points
Рис. 1 – (a) (b) исходное изображение, богатое деталями, и его функция SQF, (c) (d) (e) и (f) области исходного изображения и сжатых изображений, соответствующие точкам JND
Слика 1 – (a), (b) – оригинална слика богата детаљима и њена SQF функција, (c), (d), (e) и (f) – региони оригиналне слике и компримованих слика који одговарају JND тачкама

In the second step, the responses g_x and g_y of the grayscale image to the 2D Sobel filters are determined:

$$g_x(n,m) = f(n+1,m-1) + 2f(n+1,m) + f(n+1,m+1) \\ -[f(n-1,m-1) + 2f(n-1,m) + f(n-1,m+1)] \quad (2)$$

and

$$g_y(n,m) = f(n-1,m+1) + 2f(n,m+1) + f(n+1,m+1) \\ -[f(n-1,m-1) + 2f(n,m-1) + f(n+1,m-1)] \quad (3)$$

From the resulting g_x and g_y oriented gradient components, the MGM information is easily obtained according to:

$$MGM = \frac{1}{NM} \sum_{\forall n,m} \frac{1}{g_{\max}} \sqrt{g_x^2(n,m) + g_y^2(n,m)}, \quad (4)$$

where g_{max} is the experimentally determined maximum magnitude value, taken as g_{max}=4.472 for grayscale images with a dynamic range 0 to 1 (image **f** which is an 8-bit unsigned integer array with a range of 0 to 255 is linearly scaled to a dynamic range of 0 to 1 with a double-precision 64-bit format) (Bondžulić et al, 2021).

The PSNR JND #1 prediction is determined based on the MGM information as:

$$PSNR(MGM) = \begin{cases} 2115.5MGM^2 - 377MGM + 46.4, MGM \le 0.0896 \\ 29.58, MGM > 0.0896 \end{cases}, \quad (5)$$

and this mapping function is shown in Figure 2.

The optimal values of the coefficients in Eq. (5) were determined based on the results of subjective tests on the MCL-JCI dataset (Bondžulić et al, 2021).

Figure 2 shows that, with increasing MGM, the value of PSNR prediction decreases, where for MGM=0.0896 the mapping function reaches its minimum value ($PSNR_{min}$=29.58 dB). This can be explained by the influence of contrast and texture that are important for visibility masking estimation because in the regions that contain more non-uniform contents more distortion can be tolerated than in the regions with homogeneous content. Furthermore, block-based JPEG coding suppresses high-frequency components. In the homogeneous regions with gradual color/intensity change, the blocking artifact is visible to observers. In contrast, the distortion is less obvious in the textured regions (Jin et al, 2016).

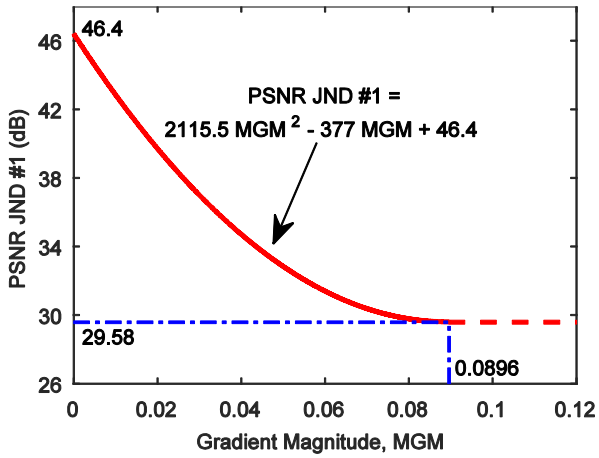


Figure 2 – PSNR prediction of the first JND point based on the mean gradient magnitude
Рис. 2 – Прогноз PSNR первой точки JND на основании средней величины градиента
Слика 2 – PSNR предикција прве JND тачке на основу средње вредности амплитуде градијента

JND prediction and image quality analysis

The described model (Bondžulić et al, 2021) was used without any additional adjustments to determine the PSNR estimates of the first JND points of the reference images from the four datasets. For example, the adopted JND model is trained on high spatial resolution images (1280x1920 pixels), and will be tested on images that are of significantly lower resolution.

Figure 3 shows the scatter plots of subjective (mean opinion score – MOS/difference MOS – DMOS) and objective (PSNR) quality scores. Each point on the scatter plots corresponds to one test image with JPEG compression. Scatter plots are shown for four image datasets, three of which are publicly available – LIVE (Sheikh et al, 2006) (with 29 original images), CSIQ (Larson & Chandler, 2010) (with 30 original images) and VCL@FER (Zarić et al, 2012) (with 23 reference images). The fourth image dataset, marked with LWIR, will be publicly available soon, and can be obtained by sending an inquiry to the authors who created it (Merrouche et al, 2018). A subset of 100 images with JPEG compression was taken from the LWIR dataset containing images from the infrared part of the electromagnetic spectrum. The LWIR dataset test images were created from 20 original images, and their quality was reduced using five degradation levels (five quality factors). In subjective tests, the scores of 31 observers were collected.

On the scatter plots, JPEG images are represented by two symbols, where the first symbol (o) corresponds to the images in which the PSNR of the test image is above the PSNR JND #1 (this is the first class of images, which should consist of high quality images, and in which there is no loss of visual information). The second symbol (Δ) corresponds to the images for which the PSNR of the test image is below the PSNR JND #1 (this is the second class of images that should consist of lower quality images). A similar idea of dividing images into two classes was used in (Ponomarenko et al, 2015).

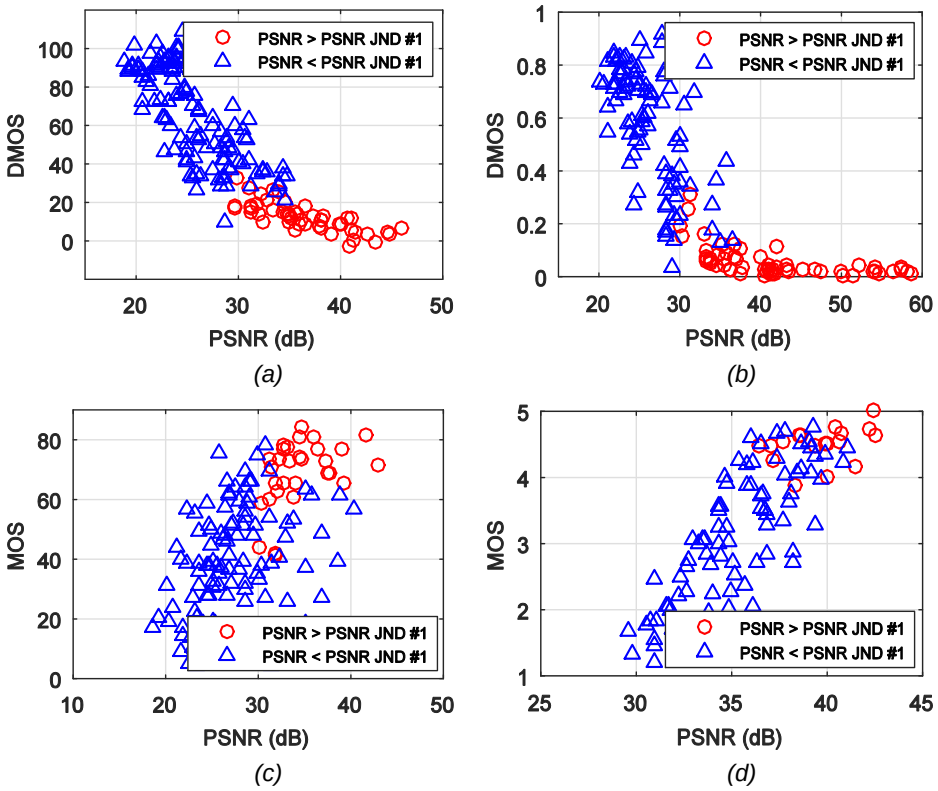


Figure 3 – Scatter plots of subjective and PSNR objective image quality scores for JPEG images from four datasets: (a) LIVE (175 images), (b) CSIQ (150 images), (c) VCL@FER (138 images) and (d) LWIR (100 images)

Рис. 3 – Диаграммы разброса субъективных оценок качества изображений и объективных оценок PSNR для изображений JPEG из четырех наборов данных: (a) LIVE (175 изображений), (b) CSIQ (150 изображений), (c) VCL@FER (138 изображений) и (d) LWIR (100 изображений)

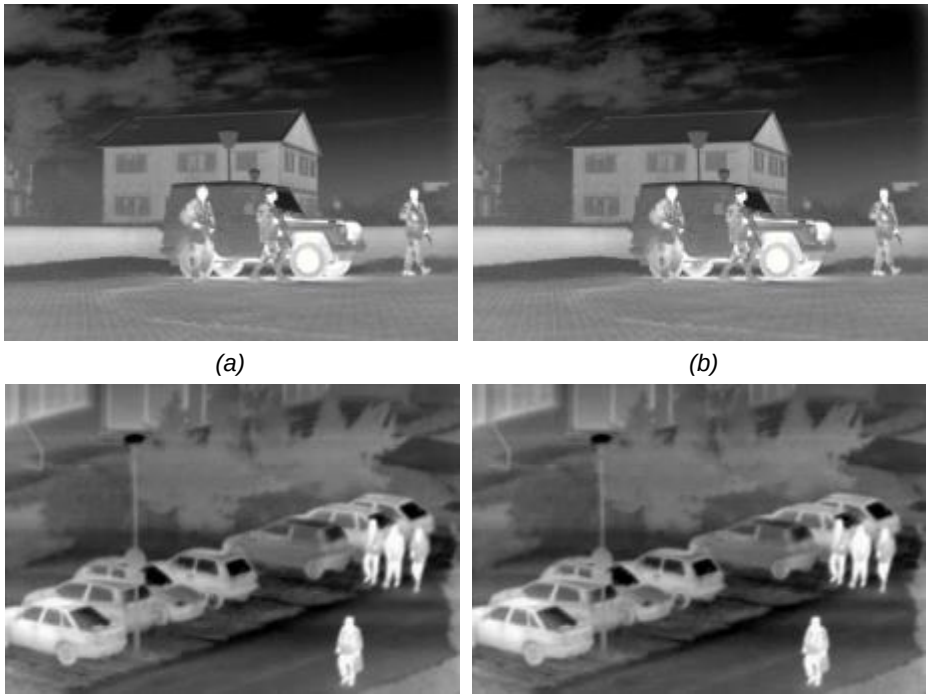
Слика 3 – Дијаграми расипања субјективних и PSNR објективних скорова квалитета JPEG слика из четири базе: (a) LIVE (175 слика), (b) CSIQ (150 слика), (c) VCL@FER (138 слика) и (d) LWIR (100 слика)

Figure 3 shows that the proposed approach for the first JND point estimation proved to be excellent on the LIVE and CSIQ datasets. By applying the PSNR of the first JND point, images of excellent visual quality were detected – they correspond to lower values of subjective DMOS scores. Slightly worse results of the proposed first JND point estimation model can be seen for the images from the VCL@FER dataset.

The surprising result of the proposed approach can be seen on the LWIR image dataset. Although it is a dataset of images from the invisible (infrared) part of the electromagnetic spectrum, the proposed approach of the first JND point estimation has proven to be very successful in detecting JPEG compressed images with high quality – they correspond to higher values of subjective MOS scores. In this way, the validity of the proposed PSNR estimation of the first JND point was indirectly confirmed, using the results of subjective quality tests of available image datasets.

Figure 4 shows two source images from the LWIR dataset and their JPEG compressed versions for which the PSNR value is above the PSNR JND #1. The test images are of excellent and good visual quality, i.e. there is no visual difference between the pair of images shown in Figures 4(a) and 4(b) (MOS=5), while the observers noticed slight differences between the pair shown in Figures 4(c) and 4(d) (MOS=4).

For the two selected examples, the degrees of image compression are approximately equal and are 21.7 (Figure 4a) and 23.3 (Figure 4b).



(a) *(b)*

(c) *(d)*

Figure 4 – (a) original image (image size is 608 kB), (b) test image with JPEG compression (PSNR=42.47, PSNR JND #1=39.92, MOS=5, image size is 28 kB), (c) original image (image size is 256 kB) and (d) test image with JPEG compression (PSNR=40.03, PSNR JND #1=38.18, MOS=4, image size is 11 kB)

Рис. 4 – (а) исходное изображение (размер изображения 608 kB), (б) тестовое изображение со сжатием JPEG (PSNR=42.47, PSNR JND #1=39.92, MOS=5, размер изображения 28 kB), (в) исходное изображение (размер изображения 256 kB) и (d) тестовое изображение со сжатием JPEG (PSNR=40.03, PSNR JND #1=38.18, MOS=4, размер изображения 11 kB)

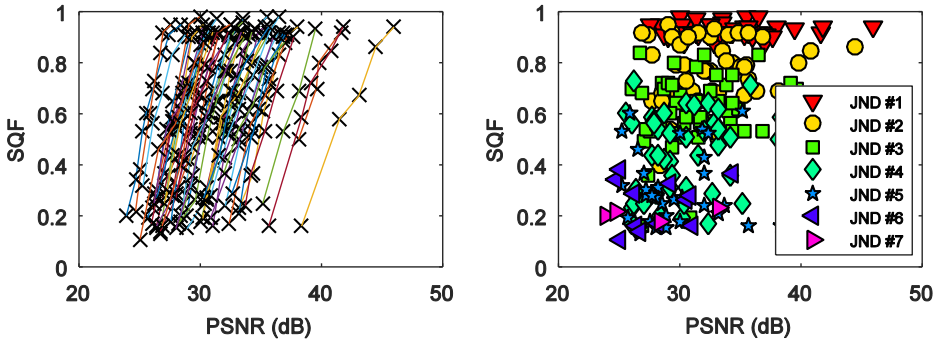
Слика 4 – (а) оригинална слика (величине 608 kB), (b) тест-слика са JPEG компресијом (PSNR=42,47, PSNR JND #1=39,92, MOS=5, величина слике је 28 kB), (c) оригинална слика (величине 256 kB) и (d) тест-слика са JPEG компресијом (PSNR=40,03, PSNR JND #1=38,18, MOS=4, величина слике је 11 kB)

Impact of JND prediction on image quality assessment

The described approach of the PSNR estimation of the first JND point is derived from the results of subjective tests of the MCL-JCI dataset (Jin et al, 2016) in which 50 original images are used. The degree of agreement between SQF subjective and objective quality scores on this JPEG image dataset is worse than the degree of agreement between subjective and objective quality scores on publicly

available image datasets such as LIVE, CSIQ, VCL@FER and similar (Bondžulić et al, 2020). A very low degree of agreement between the SQF subjective and PSNR objective quality scores on this image dataset can be observed through the large spreading on the scatter plots shown in Figure 5. The scatter plots are shown for PSNR objective quality scores. The degraded images originating from the same original image are on the scatter plot in Figure 5(a) connected by lines of different colors. On the scatter plot in Figure 5(b), the images corresponding to the JND points derived from subjective tests are marked with different symbols (from JND #1 to JND #7).

Additionally, in Figure 5(a), it can be seen that the slope of the lines corresponding to the images originating from the same original image is approximately the same. The spreading in the space of subjective and objective quality scores is a consequence of the different content of the original images. Similar conclusions related to the PSNR performance in video quality assessment were reached by the authors in (Huynh-Thu & Ghanbari, 2008), (Bondzulic et al, 2016). The goal of designing objective quality assessment measures is that the results of the assessment, among other things, do not depend on the content of the original images.



(a) *(b)*

Figure 5 – Scatter plots of subjective and PSNR objective quality scores of MCL-JCI JPEG compressed images: (a) the scatter plot is shown regarding the images originating from the same original image and (b) the scatter plot with marked JND points

Рис. 5 – Диаграммы разброса субъективных оценок качества и объективных оценок PSNR сжатых изображений MCL-JCI JPEG: (а) график разброса показан в соответствии с изображениями, происходящими из одного и того же исходного изображения, и (b) график разброса с отмеченными точками JND

Слика 5 – Дијаграми расипања субјективних и PSNR објективних скорова квалитета JPEG компримованих слика MCL-JCI базе: (а) дијаграм расипања је приказан према сликама које потичу од исте оригиналне слике и (b) дијаграм расипања са обележеним JND тачкама

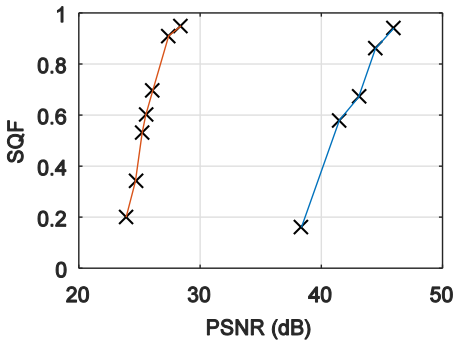
Figure 6(a) shows the curves of the JND points from the two source images, between which are the other JND points of the scatter plot between the SQF and PSNR scores on the MCL-JCI image dataset.

Figures 6(b) and 6(c) show the original images corresponding to the curves of Figure 6(a), i.e. the left and right boundaries on the scatter plot. It can be concluded that the points on the scatter plot are located between the JND points of the image with uniform regions and visible boundaries between them (right scatter border), and the image with a pronounced uniform region in the upper third of the image (with intensity saturation), and rich in details in the rest (left scatter border).

From Figure 5 it can be seen that the vertices of the curves start from the images corresponding to the first JND points. In order to make the result of the PSNR objective quality evaluation independent of the content of the original images, it is reasonable to define the differential PSNR as the difference between the PSNR and the estimation of the PSNR JND #1:

$$DPSNR = PSNR - PSNR\ JND\ \#1. \quad (6)$$

DPSNR values can be both positive and negative. Positive values correspond to good quality images (PSNR>PSNR JND #1), while negative values correspond to lower quality images. Also, DPSNR is a picture-wise JND measure of objective image quality assessment.



(a)

(b) *(c)*

Figure 6 – (a) the relationship between SQF and PSNR for the two source images of the MCL-JCI dataset, (b) the original image corresponding to the left boundary of the JND points and (c) the original image corresponding to the right boundary of the JND points of the MCL-JCI image dataset

Рис. 6 – (а) взаимосвязь между SQF и PSNR для двух исходных изображений набора данных MCL-JCI, (b) исходное изображение, соответствующее левой границе точек JND, и (c) исходное изображение, соответствующее правой границе JND-точки набора данных изображения MCL-JCI

Слика 6 – (а) веза између SQF и PSNR за две изворне слике из MCL-JCI базе, (b) оригинална слика која одговара левој граници JND тачака и (c) оригинална слика која одговара десној граници JND тачака MCL-JCI базе слика

The scatter plots of subjective and DPSNR objective quality scores on the four analyzed image datasets are shown in Figure 7. Significantly less spreading of scores is observed in relation to the spreading of the scores of the PSNR objective measure (Figure 3).

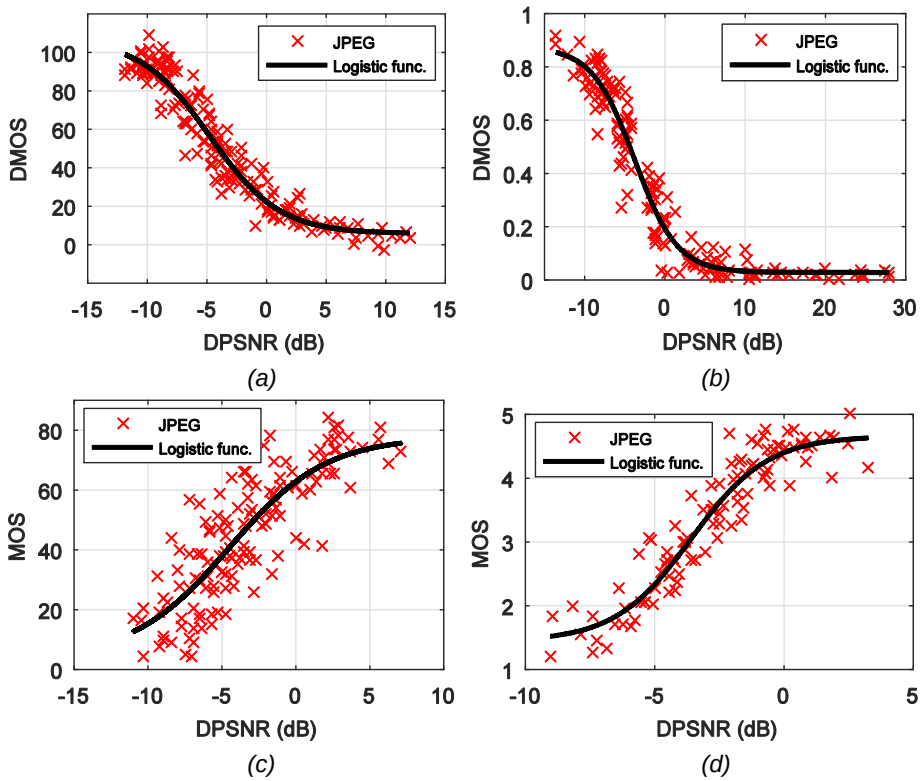


Figure 7 – Scatter plots of subjective and DPSNR objective quality scores of images with JPEG compression on four datasets: (a) LIVE, (b) CSIQ, (c) VCL@FER and (d) LWIR
Рис. 7 – Диаграммы разброса субъективных и объективных оценок качества DPSNR изображений со сжатием JPEG для четырех наборов данных: (a) LIVE, (b) CSIQ, (c) VCL@FER и (d) LWIR
Figure 7 – Дијаграми расипања субјективних и DPSNR објективних скорова квалитета слика са JPEG компресијом за четири базе: (a) LIVE, (b) CSIQ, (c) VCL@FER и (d) LWIR

Table 1 provides the quantitative indicators of the degree of agreement between the subjective and PSNR/DPSNR objective quality scores for the four analyzed image datasets. The linear correlation coefficient (LCC), Spearman's rank-order correlation (SROCC), mean absolute error (MAE), root mean square error (RMSE) and outlier ratio (OR) between the subjective and objective quality scores after nonlinear regression using a logistic function with four parameters were used as quantitative indicators (ITU-T, 2004), (Bondžulić et al, 2018). In addition to the performance of these two objective measures, the performance of the HVS-based objective measures is given: PSNR-HVS (Egiazarian et al, 2006), PSNR-HVS-M (Ponomarenko et al, 2007) and WNMAE

(Huang et al, 2018). PSNR-HVS and PSNR-HVS-M measures are sub-band models that take into account the contrast sensitivity function. Additionally, PSNR-HVS-M takes into account the between-coefficient contrast masking of the discrete cosine transform basis functions (Ponomarenko et al, 2007). WNMAE is a traditional pixel-wise model based on JND. Through this measure, HVS's physiological (color and light sensitivity) and psycho-physiological (texture and edge sensitivity) characteristics were implemented. The two best results for each dataset and for each quantitative indicator are in Table 1 marked in bold.

Table 1 – Performance comparison of objective measures on four datasets
Таблица 1 – Сравнение эффективности объективных показателей по четырем наборам данных
Табела 1 – Поређење перформанси објективних мера на четири базе

Dataset	Measure	LCC	SROCC	MAE	RMSE	OR [%]
LIVE	PSNR	0.8879	0.8809	11.3594	14.6532	12.5714
	DPSNR	**0.9649**	**0.9565**	**6.5225**	**8.3637**	**1.1429**
	PSNR-HVS	0.9585	0.9478	7.1802	9.0760	**1.1429**
	PSNR-HVS-M	**0.9752**	**0.9650**	**5.5549**	**7.0493**	**0.0000**
	WNMAE	0.9143	0.9113	9.9537	12.9013	5.7143
CSIQ	PSNR	0.8906	0.8879	0.0964	0.1391	31.3333
	DPSNR	**0.9707**	**0.9510**	**0.0547**	**0.0735**	**19.3333**
	PSNR-HVS	0.9577	0.9400	0.0603	0.0880	22.6667
	PSNR-HVS-M	**0.9733**	**0.9512**	**0.0501**	**0.0702**	**20.0000**
	WNMAE	0.8971	0.8962	0.0946	0.1352	34.0000
VCL@FER	PSNR	0.6041	0.6040	13.6027	16.7039	69.5652
	DPSNR	0.8269	0.8262	9.2646	11.7856	52.1739
	PSNR-HVS	**0.8741**	**0.8775**	**7.8178**	**10.1823**	**48.5507**
	PSNR-HVS-M	**0.9408**	**0.9388**	**5.5695**	**7.1051**	**33.3333**
	WNMAE	0.6252	0.6279	13.2803	16.3580	71.7391
LWIR	PSNR	0.8377	**0.8146**	**0.4362**	0.5650	**59.0000**
	DPSNR	**0.9481**	**0.9238**	**0.2596**	**0.3290**	**45.0000**
	PSNR-HVS	0.8238	0.8018	0.4573	0.5865	63.0000
	PSNR-HVS-M	**0.8389**	0.8135	0.4492	**0.5631**	65.0000
	WNMAE	Not applicable				

The performance of the DPSNR objective measure is significantly better than the performance of the PSNR, for all five quantitative indicators and on four datasets. It can be noticed that the performance of the DPSNR is the worst on the VCL@FER image dataset, where the original PSNR has the worst results.

The DPSNR performance is at the top on the LIVE and CSIQ datasets, along with the PSNR-HVS-M measure. Two sub-band models provide the best results on the VCL@FER image dataset, while the performance of the proposed DPSNR approach is best on the LWIR dataset of images from the infrared part of the electromagnetic spectrum. The performance of the WNMAE objective measure is slightly better than the performance of the worst ranked PSNR objective measure.

A careful reader may notice that in comparing the results of objective measures between different datasets (Table 1) one should be careful because different grading scales in subjective experiments have been used on different datasets (see Figures 3 and 5). The dynamic range of the grading scale affects the MAE and the RMSE. In this case, the LCC and SROCC values are relevant for comparing the results between the datasets.

The performance of objective measures was additionally analyzed on the MCL-JCI image dataset, which was used to train the estimation algorithms of the first JND point. Figure 8 shows the scatter plots of the SQF subjective and PSNR objective quality scores with image division into two classes, using PSNR JND #1 values estimated using the approaches described in (Bondžulić et al, 2021) and (Lin et al, 2020).

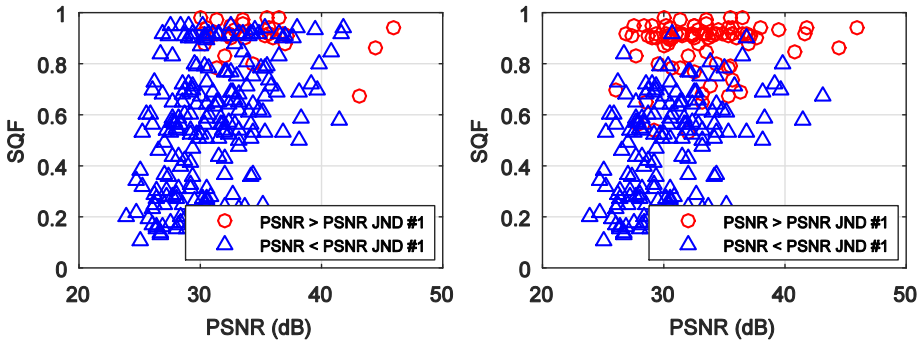


Figure 8 – Scatter plots of SQF subjective and PSNR objective scores on the MCL-JCI image dataset with division of images into two classes, where the estimates of PSNR JND #1 were determined based on: (a) approach (Bondžulić et al, 2021) and (b) approach (Lin et al, 2020)

Рис. 8 – Диаграммы разброса субъективных оценок SQF и объективных оценок PSNR в наборе данных изображений MCL-JCI с разделением изображений на два класса, где оценки PSNR JND #1 были определены на основании: (а) подхода (Bondžulić et al, 2021) и (б) подхода (Lin et al, 2020)

Слика 8 – Дијаграми расипања SQF субјективних и PSNR објективних скорова на MCL-JCI бази са поделом на две класе слика, где се за одређивање PSNR JND #1 користи: (а) приступ из (Bondžulić et al, 2021) и (b) приступ из (Lin et al, 2020)

From Figure 8 it can be concluded that, by applying the approach (Lin et al, 2020), more JND #1 points are detected than by applying the approach (Bondžulić et al, 2021) (additionally, see Figure 5(b)). It can also be observed that using this approach, several other (higher) JND points that are above the threshold of visible differences (PSNR JND #1) were detected.

The values of the DPSNR objective measure were determined on the basis of two estimates of PSNR JND #1 – the approaches described in (Bondžulić et al, 2021) and (Lin et al, 2020). The scatter plots of the SQF and DPSNR scores on the MCL-JCI dataset and the corresponding logistic functions are shown in Figure 9, while the quantitative indicators of the degree of their agreement are given in Table 2.

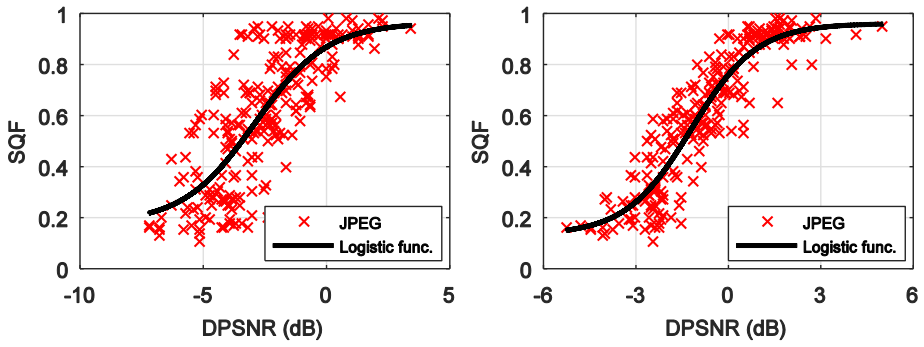


Figure 9 – Scatter plots of subjective and DPSNR objective scores on the MCL-JCI image dataset where the estimates of PSNR JND #1 were determined based on: (a) approach (Bondžulić et al, 2021) and (b) approach (Lin et al, 2020)

Рис. 9 – Диаграммы разброса субъективных оценок и объективных оценок DPSNR в наборе данных изображений MCL-JCI, где оценки PSNR JND #1 были определены на основании: (a) подхода (Bondžulić et al, 2021) и (b) подхода (Lin et al, 2020)

Слика 9 – Дијаграми расипања субјективних и DPSNR објективних скорова MCL-JCI базе слика, где се за одређивање PSNR JND #1 користи: (а) приступ из (Bondžulić et al, 2021) и (b) приступ из (Lin et al, 2020)

From Figure 9 and from Table 2, it can be noticed that there is a significantly higher degree of agreement between the SQF and DPSNR objective quality scores determined using the PSNR JND #1 estimates based on the approach from (Lin et al, 2020). This result could be expected because this approach has a mean absolute PSNR JND #1 estimation error of 0.58 dB on the MCL-JCI image dataset, while the approach described in (Bondžulić et al, 2021) has a higher estimation error (1.21 dB). In this case, although the poor performance of the

baseline PSNR measure (LCC=0.4721), using PSNR JND #1 the performance of DPSNR was significantly increased and exceeded the performance of other measures (LCC=0.9194).

Table 2 – Performance comparison of the objective measures on the MCL-JCI dataset
Таблица 2 – Сравнение производительности объективных показателей в наборе данных MCL-JCI
Табела 2 – Поређење перформанси објективних мера на MCL-JCI бази слика

Dataset	Measure	LCC	SROCC	MAE	RMSE
MCL-JCI	PSNR	0.4721	0.4486	0.1907	0.2288
	DPSNR (Bondžulić et al, 2021)	0.7973	0.7930	0.1222	0.1566
	DPSNR (Lin et al, 2020)	**0.9194**	**0.9144**	**0.0779**	**0.1021**
	PSNR-HVS	0.7679	0.7506	0.1328	0.1662
	PSNR-HVS-M	**0.8584**	**0.8456**	**0.1026**	**0.1331**
	WNMAE	0.4783	0.4665	0.1899	0.2279

Although the introduction of the objective measure DPSNR has significantly improved the degree of agreement between subjective and PSNR objective quality scores, there is still room for improvement, and the degree of improvement will depend on the accuracy of PSNR JND #1 estimation.

The position of the threshold of visible differences introduced in the quality assessment through PSNR JND #1, in this paper improved the performance of PSNR on the class of images with JPEG compression. This is a consequence of reducing the dependence of objective estimates on the content of the source signal. We expect that with reliable estimation of the position of PSNR JND #1 for other image classes (types of degradation), the performance of PSNR of individual classes will be improved, as well as the performance on a global level (reducing the dependence of estimates on the type of degradation).

Conclusion

The paper analyzes the reliability of one approach/model for the peak signal-to-noise ratio estimation of the visible differences (JND #1 point) of images with JPEG compression. Reliability was confirmed in an indirect way by using the results of subjective tests of five available image datasets, i.e. it has been shown that by applying a peak signal-to-noise ratio of the first JND point, high quality images can be detected. As the proposed approach was derived on one of the analyzed image datasets, and the success was confirmed on the four remaining ones, it

can be concluded that the findings derived from subjective tests on one dataset can be successfully used on other related datasets.

The paper additionally shows that the performance of the peak signal-to-noise ratio as a measure of objective quality assessment can be improved by taking into account the PSNR values of the first JND point. Improvement was achieved on image datasets with JPEG compression, through a significant increase in the degree of agreement between subjective and objective quality scores. Also, it has been shown that improving the accuracy of the estimation of the first JND point has a positive effect on the degree of agreement between subjective and objective assessments. Therefore, future work will be focused on improving the accuracy of the PSNR estimation of the threshold of visible differences, both for images with JPEG compression and for images with other types of degradation.

To the best of our knowledge, this is the first attempt to use JND information in quality assessment at the picture-wise level. Previous models have used pixel-based or sub-band JND visibility thresholds. The additional significance of the paper is reflected in the idea to indirectly analyze the success of the JND model through two-class image separation without conducting subjective tests, i.e. using already available subject-rated image datasets. Finally, the results are presented on JPEG compressed images originating from the visible and from the infrared part of the electromagnetic spectrum, which is of interest for remote sensing and surveillance applications.

References

Ahar, A., Mahmaoudpour, S., Van Wallendael, G., Paridaens, T., Lambert, P. & Schelkens, P. 2018. A just noticeable difference subjective test for high dynamic range images. In: *Proceedings of Tenth International Conference on Quality of Multimedia Experience (QoMEX)*, Cagliari, Italy, pp.1-6, May 29-June 1. Available at: https://doi.org/10.1109/QoMEX.2018.8463429.

Bondžulić, B.P., Pavlović, B.Z., Andrić, M.S. & Petrović, V.S. 2017. Comments on objective quality assessment of JPEG images with visible differences. In: *Proceedings of 13th International Conference on Advanced Technologies, Systems and Services in Telecommunications (TELSIKS)*, Niš, Serbia, pp.455-458, October 18-20. Available at: https://doi.org/10.1109/TELSKS.2017.8246323.

Bondžulić, B., Pavlović, B. & Petrović, V. 2018. Performance analysis of full-reference objective image and video quality assessment metrics. *Vojnotehnički glasnik/Military Technical Courier*, 66(2), pp.322-350. Available at: https://doi.org/10.5937/vojtehg66-12708.

Bondzulic, B., Pavlovic, B., Petrovic, V. & Andric, M. 2016. Performance of peak signal-to-noise ratio quality assessment in video streaming with packet losses. *Electronics Letters*, 52(6), pp.454-456. Available at: https://doi.org/10.1049/el.2015.3784.

Bondžulić, B., Stojanović, N., Petrović, V. & Zelmati, O. 2020. Using objective image quality assessment metrics in detection just noticeable differences of JPEG images. In: *Proceedings of XXVI Conference and Exhibition YU INFO 2020*, Kopaonik, Serbia, pp.203-208, March 8-11 [online]. Available at: http://www.yuinfo.org/ZBORNIK_YU_INFO_2020.pdf (in Serbian) [Accessed: 1 November 2021].

Bondžulić, B., Stojanović, N., Petrović, V., Pavlović, B. & Miličević, Z. 2021. Efficient prediction of the first just noticeable difference point for JPEG compressed images. *Acta Polytechnica Hungarica*, 18(8), pp.201-220. Available at: https://doi.org/10.12700/APH.18.8.2021.8.11.

Egiazarian, K., Astola, J., Ponomarenko, N., Lukin, V., Battisti, F. & Carli, M. 2006. Two new full-reference quality metrics based on HVS. In: *Proceedings of 2nd International Workshop on Video Processing and Quality Metrics for Consumer Electronics – VPQM*, Scottsdale, Arizona, USA, pp.1-4, January 22-24.

Fan, C., Lin, H., Hosu, V., Zhang, Y., Jiang, Q., Hamzaoui, R. & Saupe, D. 2019. SUR-Net: Predicting the satisfied user ratio curve for image compression with deep learning. In: *Proceedings of 11th International Conference on Quality of Multimedia Experience*, Berlin, Germany, pp.1-6, June 5-7. Available at: https://doi.org/10.1109/QoMEX.2019.8743204.

Gonzalez, R.C. & Woods, R.E. 2018. *Digital image processing, 4th Edition*. London: Pearson Education, Inc. ISBN-13: 9780133356724.

Huang, J., Feng, H., Xu, Z., Li, Q. & Chen, Y. 2018. A robust deblurring algorithm for noisy images with just noticeable blur. *Optik – International Journal for Light and Electron Optics*, 168, pp.577-589. Available at: https://doi.org/10.1016/j.ijleo.2018.04.052.

Hudson, G., Leger, A., Niss, B. & Sebestyen, I. 2017. JPEG at 25: Still going strong. *IEEE MultiMedia*, 24(2), pp.96-103. Available at: https://doi.org/10.1109/MMUL.2017.38.

Hudson, G., Leger, A., Niss, B., Sebestyen, I. & Vaaben, J. 2018. JPEG-1 standard 25 years: Past, present, and future reasons for a success. *Journal of Electronic Imaging*, 27(4), art.number:040901. Available at: https://doi.org/10.1117/1.JEI.27.4.040901.

Huynh-Thu, Q. & Ghanbari, M. 2008. Scope of validity of PSNR in image/video quality assessment. *Electronics Letters*, 44(13), pp.800-801. Available at: https://doi.org/10.1049/el:20080522.

-ITU-T (Telecommunication Standardization Sector of ITU). 2004. *Objective perceptual assessment of video quality: Full reference television*. [online]. Available at: https://www.itu.int/ITU-T/studygroups/com09/docs/tutorial_opavc.pdf [Accessed: 1 November 2021].

Jin, L., Lin, J.Y., Hu, S., Wang, H., Wang, P., Katsavounidis, I., Aaron, A. & Kuo, C.-C. J. 2016. Statistical study on perceived JPEG image quality via MCL-JCI dataset construction and analysis. In: *Proceedings of IS&T International Symposium on Electronic Imaging – Image Quality and System Performance XIII*, San Francisco, CA, USA, art.number:IQSP-222, February 14-18. Available at: https://doi.org/10.2352/ISSN.2470-1173.2016.13.IQSP-222.

Larson, E.C. & Chandler, D.M. 2010. Most apparent distortion: Full-reference image quality assessment and the role of strategy. *Journal of Electronic Imaging*, 19(1), art.number:011006. Available at: https://doi.org/10.1117/1.3267105.

Li, H., Jenadeleh, M., Chen, G., Reips, U-D., Hamzaoui, R. & Saupe, D. 2020. Subjective assessment of global picture-wise just noticeable difference. In: *Proceedings of IEEE International Conference on Multimedia & Expo Workshops*, London, UK, pp.1-6, July 6-10. Available at: https://doi.org/10.1109/ICMEW46912.2020.9106058.

Lin, H., Hosu, V., Fan, C., Zhang, Y., Mu, Y., Hamzaoui, R. & Saupe, D. 2020. SUR-FeatNet: Predicting the satisfied user ratio curve for image compression with deep feature learning. *Quality and User Experience*, 5(5), pp.1-23. Available at: https://doi.org/10.1007/s41233-020-00034-1.

Liu, X., Chen, Z., Wang, X., Jiang, J. & Kwong, S. 2018. JND-Pano: database for just noticeable difference of JPEG compressed panoramic images. In: Hong, R., Cheng, W.H., Yamasaki, T., Wang, M. & Ngo, C.W. (Eds.) *Advances in Multimedia Information Processing. PCM 2018. Lecture Notes in Computer Science*, 11164, pp.458-468. Springer, Cham. Available at: https://doi.org/10.1007/978-3-030-00776-8_42.

Liu, H., Zhang, Y., Zhang, H., Fan, C., Kwong, S., Kuo, C-C.J. & Fan, X. 2020. Deep learning based picture-wise just noticeable prediction model for image compression. *IEEE Transactions on Image Processing*, 29, pp.641-656. Available at: https://doi.org/10.1109/TIP.2019.2933743.

Lu, G., Zhang, X., Ouyang, W., Chen, L., Gao, Z. & Xu, G. 2021. An end-to-end learning framework for video compression. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 43(10), pp.3292-3308. Available at: https://doi.org/10.1109/TPAMI.2020.2988453.

Merrouche, S., Bondžulić, B., Andrić, M. & Bujaković, D. 2018. Description and analysis of infrared image database – Subjective and objective image quality assessment. In: *Proceedings of 8th International Scientific Conference on Defensive Technologies – OTEH*, Belgrade, Serbia, pp.307-313, October 11-12 [online]. Available at: http://www.vti.mod.gov.rs/oteh18/elementi/rad/058.htm [Accessed: 1 November 2021].

Pennebaker, W.B. & Mitchell, J.L. 1993. *JPEG: Still image data compression standard*. New York: Van Nostrand Reinhold Publishers. ISBN: 0-442-01272-1.

Ponomarenko, N., Lukin, V., Astola, J. & Egiazarian, K. 2015. Analysis of HVS-metrics' properties using color image database TID2013. In: Battiato, S., Blanc-Talon, J., Gallo, G., Philips, W., Popescu, D. & Scheunders, P. (Eds.) *Advanced Concepts for Intelligent Vision Systems. ACIVS 2015. Lecture Notes in Computer Science*, 9386, pp.613-624. Springer, Cham. Available at: https://doi.org/10.1007/978-3-319-25903-1_53.

Ponomarenko, N., Silvestri, F., Egiazarian, K., Carli, M., Astola, J. & Lukin, V. 2007. On between-coefficient contrast masking of DCT basis functions. In: *Proceedings of 3rd International Workshop on Video Processing and Quality Metrics for Consumer Electronics – VPQM*, Scottsdale, Arizona, USA, pp.1-4, January 25-26 [online]. Available at: http://ponomarenko.info/vpqm07_p.pdf [Accessed: 1 November 2021].

Seo, S., Ki, S. & Kim, M. 2021. A novel just-noticeable-difference-based saliency-channnel attention residual network for full-reference image quality predictions. *IEEE Transactions on Circuits and Systems for Video Technology*, 31(7), pp.2602-2616. Available at: https://doi.org/10.1109/TCSVT.2020.3030895.

Sheikh, H.R., Sabir M.F. & Bovik, A.C. 2006. A statistical evaluation of recent full reference image quality assessment algorithms. *IEEE Transactions on Image Processing*, 15(11), pp.3440-3451. Available at: https://doi.org/10.1109/TIP.2006.881959.

Tian, T., Wang, H., Zuo, L., Kuo, C-C.J. & Kwong, S. 2020. Just noticeable difference level prediction for perceptual image compression. *IEEE Transactions on Broadcasting*, 66(3), pp.690-700. Available at: https://doi.org/10.1109/TBC.2020.2977542.

Toprak, S. & Yalman, Y. 2017. A new full-reference image quality metric based on just noticeable difference. *Computer Standards & Interfaces*, 50, pp.18-25. Available at: https://doi.org/10.1016/j.csi.2016.08.003.

Wallace, G.K. 1992. The JPEG still picture compression standard. *IEEE Transactions on Consumer Electronics*, 38(1), pp.18-34. Available at: https://doi.org/10.1109/30.125072.

Wang, Z., Tran, T-H., Muthappa, P.K. & Simon, S. 2019. A JND-based pixel-domain algorithm and hardware architecture for perceptual image coding. *Journal of Imaging*, 5(50), pp.1-29. Available at: https://doi.org/10.3390/jimaging5050050.

Yu, H. & Winkler, S. 2013. Image complexity and spatial information. In: *Proceedings of 5th 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.

Zarić, A., Tatalović, N., Brajković, N., Hlevnjak, H., Lončarić, M., Dumić, E. & Grgić, S. 2012. VCL@FER image quality assessment database. *Automatika*, 53(4), pp.344-354. Available at: https://doi.org/10.7305/automatika.53-4.241.

ПРИМЕНЕНИЕ ПОРОГОВОЙ МОДЕЛИ ПРОГНОЗИРОВАНИЯ ЗАМЕТНЫХ РАЗЛИЧИЙ ПРИ ОЦЕНКЕ КАЧЕСТВА СЖАТЫХ ИЗОБРАЖЕНИЙ В ФОРМАТЕ JPEG

Бобан П. Бонджулич[а], *Бобан* З. Павлович[а], **корреспондент**,
Ненад М. Стоянович[а], *Владимир* С. Петрович[б]

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

[б] Нови-Садский университет, факультет технических наук, г. Нови-Сад, Республика Сербия

РУБРИКА ГРНТИ: 49.00.00 СВЯЗЬ:
49.40.00 Системы передачи движущихся изображений;
49.40.37 Техника кодирования и передачи изображения
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В данной статье представлено интересное исследование, связанное с анализом пороговой модели прогнозирования заметных различий (JND) на изображениях и ее применением для оценки качества изображений со сжатием JPEG.

Методы: Анализ производительности модели JND был проведен косвенным способом с использованием общедоступных баз изображений с результатами субъективных тестов, при разделении изображений по двум категориям (выше и ниже порога заметных различий). При анализе производительности модели прогнозирования JND и оценке качества изображения использовались пять баз изображений, четыре из которых относятся к видимому диапазону длин волн, а одна база изображений, предназначенная для дистанционного наблюдения, была из инфракрасной части электромагнитного спектра.

Результаты: В данной статье показано, что применение моделей JND может использоваться для оценки субъективных показателей качества с большей точностью, что приводит к значительному улучшению характеристик традиционного соотношения пикового сигнала к шуму (PSNR). Среднее значение коэффициента линейной корреляции (по пяти базам) между субъективными и объективными оценками качества PSNR увеличилось с 74% (традиционный PSNR) до 90% (PSNR с моделью JND на уровне изображения). Выигрышный результат, достигаемый за счет внедрения модели JND на уровне изображения в объективной оценке, зависит от выбранной базы и результатов исходной простой меры PSNR, был получен по всем пяти базам.

Выводы: Дополнительное улучшение объективной меры, основанной на JND, может быть достигнуто за счет улучшения наглядной модели прогнозирования JND.

Ключевые слова: порог заметных различий, сжатие JPEG, пиковое соотношение сигнал/шум, субъективная и объективная оценка качества изображения.

ПРИМЕНА МОДЕЛА ПРЕДИКЦИЈЕ ПРАГА УОЧЉИВИХ РАЗЛИКА У ПРОЦЕНИ КВАЛИТЕТА СЛИКА СА JPEG КОМПРЕСИЈОМ

Бобан П. Бонџулић[а], *Бобан* З. Павловић[а], **аутор за преписку**, *Ненад* М. Стојановић[а], *Владимир* С. Петровић[б]

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

[б] Универзитет у Новом Саду, Факултет техничких наука, Нови Сад, Република Србија

ОБЛАСТ: телекомуникације
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У раду су представљена интересантна истраживања која се односе на анализу перформанси модела предикције прага уочљивих разлика (JND) на нивоу слике и његову примену у процени квалитета слика са JPEG компресијом.

Методе: Анализа перформанси JND модела спроведена је на индиректан начин кроз занимљиву идеју да се користе јавно доступне базе слика са резултатима субјективних тестова, са поделом слика на две класе (изнад и испод прага уочљивих разлика). У анализи перформанси предикције JND модела и при процени квалитета коришћено је пет база слика, од којих четири потичу из видљивог опсега таласних дужина, док је једна база са сликама из инфрацрвеног дела електромагнетног спектра намењених даљинском осматрању и надзору.

Резултати: У раду је показано да се применом JND модела са већом прецизношћу могу естимирати субјективни скорови квалитета, што води значајном побољшању перформанси традиционалног вршног односа сигнал/шум (PSNR). Добитак остварен увођењем JND модела на нивоу слике у објективну процену зависи од изабране базе и резултата полазне једноставне PSNR мере, а остварен је на свих пет база. Средња вредност коефицијента линеарне корелације (за пет база) између субјективних и PSNR објективних естимација квалитета је са 74%

Bondžulić, B. et al, Picture-wise just noticeable difference prediction model for JPEG image quality assessment, pp.62-86

(традиционални PSNR) порасла на 90% (PSNR са JND моделом на нивоу слике).

Закључак: Додатно унапређење JND засноване објективне мере може се добити унапређењем модела предикције JND.

Кључне речи: праг уочљивих разлика, JPEG компресија, вршни однос сигнал/шум, субјективна и објективна процена квалитета слике.

Paper received on / Дата получения работы / Датум пријема чланка: 02.11.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 03.01.2022.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 04.01.2022.

IMPLEMENTATION OF THE DIGITAL TRAINING CONCEPT IN THE BASIC FLIGHT TRAINING IN THE SERBIAN MILITARY ACADEMY

Slaviša I. Vlačić[a], *Aleksandar* Z. Knežević[b], *Vladimir* M. Grbović[c], *Panos* A. Vitsas[d], *Mihajlo (Mike)* S. Mihajlovic[e]

[a] University of Defence in Belgrade, Military Academy, Air Force Department, Belgrade, Republic of Serbia, e-mail: slavisa.vlacic@va.mod.gov.rs, **corresponding author**, ORCID iD: https://orcid.org/0000-0001-9336-0512

[b] University of Defence in Belgrade, Military Academy, Air Force Department, Belgrade, Republic of Serbia, e-mail: aleksandar.knezevic@va.mod.gov.rs, ORCID iD: https://orcid.org/0000-0001-6786-4530

[c] Serbian Armed Forces, Air Force and Air Defence Command, Belgrade, Republic of Serbia, e-mail: grba74@yahoo.com, ORCID iD: https://orcid.org/0000-0003-1700-2478

[d] International Test Pilots School, London ON, Canada, e-mail: pavitsas@gmail.com, ORCID iD: https://orcid.org/0000-0001-5266-4640

[e] Government of Ontario, Toronto ON, Canada; MRTD Defense Eng, Toronto ON, Canada, e-mail: mmihajlovic@rogers.com, ORCID iD: https://orcid.org/0000-0001-8768-676X

DOI: 10.5937/vojtehg70-34610; https://doi.org/10.5937/vojtehg70-34610

FIELD: Air traffic, Information technologies
ARTICLE TYPE: Original scientific paper

Abstract:

Introduction/purpose: The paper provides a review of recent research in the field of digital training applied in the Serbian Military Academy flight training. Flight training represents the foundation of successful education of military pilots. Its division is based on the environment and a phase of realization. The main part and the core of successful flight training is basic flight training. This training phase has experienced significant changes with the introduction of the Technically Advanced aircraft (TAA) which is characterized by a high degree of digitalization not only of the cockpit but also of other aircraft systems. Consequently, a different methodological approach to training is needed, including a digital training concept. The paper shows the achievements and certain solutions based on some

elements of digital training concepts used in the basic flight training at the Serbian Military Academy.

Methods: The scientific approach is used in the evaluation of aircraft cockpit digitalization and in the implementation of a new training concept in the basic flight training in the Serbian Military Academy.

Results: Based on the methodological analysis used, the importance and the values of the digital training concept in basic flight training are shown.

Conclusion: Although the digital training concept is not mandatory in the existing flight training model in the Serbian Military Academy, it proves to be a valuable asset. Its potential is significant and, to a certain extent, it can change the nature of basic flight training. Due to digital training, cadets can fly more safely and their flying skills are acquired faster. In accordance with new modern aircraft acquisition in the Serbian Air Force, every aspect of the digital training concept has to be carefully considered, especially in the basic flight training phase, including conversion to new aircraft types.

Key words: flight training, glass cockpit, digital training, training devices.

Introduction

Flight training represents the foundation of successful education of military pilots. Its division is based on the environment and a phase of realization. Regarding the environment, it can be realized on the ground or in the air. Military flight training consists of four phases: primary, basic, advanced, and combat flight training. The main part and the core of successful flight training is basic flight training. This phase is usually completed on a piston-engine or turboprop trainer. Acquisitions of new types of planes in this phase involve many changes and bring new challenges. It is necessary to adapt the methodological manuals, the study curriculum and the syllabus based on the Lasta airplane as well as many other elements of the flight training system. In recent years, the biggest challenge has been the introduction of a digital glass cockpit from the very beginning of flight training. It demands a new approach, even using a variety of commercially available tools and devices to make the digital concept effective for a new era of basic flight training.

Basic flight training in the Military Academy

In the Military Academy, the study in military aviation is divided in two main parts. The first one, lasting five semesters, is realized in the Military Academy headquarters situated in Belgrade. The main goal of

this phase is theoretical preparation for the upcoming flight training in an airbase near Belgrade. This phase is also considered as a preparation phase in terms of core activities (flying) during studying. The second phase is flight training on airplanes and helicopters and it is crucial for the cadets - pilots. Having in mind that the first (preparation) phase has a very important role regarding the quality of flight training as a crown of the education process, there is a permanent task to improve this process and make it more effective and safer (Vlacic et al, 2014).

Flight training represents the foundation of successful education of military pilots. The main constituents of flight training are the environment and a phase of realization. Regarding the environment, it can be realized on the ground or in the air. Military flight training consists of four phases: primary, basic, advanced, and combat flight training.

Basic flight training is considered to be the most important phase of flight training and the core of the successful process of making future pilots. It is aimed at mastering the necessary aircraft handling skills. The curriculum contains basic flying, aerobatic flying, navigation flying, instrument flying, formation flying, and night flying. The flight training duration is between 80 and 130 flight hours, and it depends on the airplane or helicopter types. These can be piston engine or turboprop airplanes, even simple jet trainers or helicopters.

The first step for each of these phases is the ground (theoretical) preparation, which is an integral part of flight training. The division by the phases has not been changed for almost half a century and it would not be changed in the near future. The main teaching methods in the air have not been changed, either. However, the main changes have emerged because of the introduction of new training aircraft, regardless of airplane or helicopter types (Vlačić et al, 2015).

Recognizing the importance of the basic type of training, the Serbian Air Force very carefully approached the design of a new type of piston engined aircraft, named Lasta. This type of aircraft has been included in the Military Academy's flight training syllabus since 2017. The syllabus is based on two aircraft types during the training in the Academy: the basic flight training on the Lasta (Swallow) aircraft precedes the training on the advanced jet trainer G-4 (Figure 1) followed by the basic combat training and the introduction to fighter fundamentals (IFF).

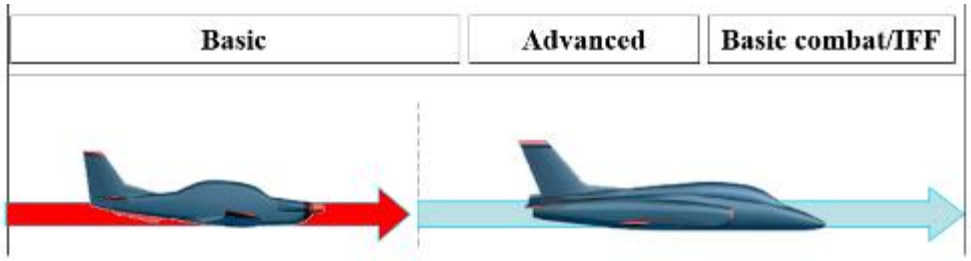


Figure 1 – Basic flight training on the Lasta precedes the training on the G-4
Рис. 1 – Основная летная подготовка на самолете „Ласта“, предшествующая учениям на „Г-4“.
Слика 1 – Основна летачка обука на авиону„ласта” претходи обуци на Г-4

The Lasta training aircraft, as a new type in the Serbian Air Force service, brings a lot of technical improvements compared to older training aircraft. One of the biggest improvements is the implementation of a digital glass cockpit (Figure 2).

Figure 2 – Digital cockpit of the Lasta aircraft
Рис. 2 – Стеклянная кабина самолета „Ласта“
Слика 2 – Дигитални кабински простор авиона „ласта”

Lasta's glass cockpit includes the most modern navigation and communications equipment currently available on the market for this category of aircraft. Although the flight characteristics of the Lasta aircraft are adapted to beginners, the technical level of the aircraft equipment mentioned above requires a great effort towards achieving the required level of confidence and safe operating. It was necessary to make adaptations of the methodological manuals, the study curriculum and the syllabus concerning the Lasta airplane, as well as many other elements of the flight training system.

Digital glass cockpit

A glass cockpit is an aircraft cockpit that features electronic (digital) instrument displays, typically large LCD screens, rather than the traditional style of analog dials and gauges. While a traditional cockpit is based on numerous mechanical gauges to display information, a glass cockpit uses several displays driven by flight management systems that can be adjusted to display flight information as needed. This simplifies aircraft operation and navigation and allows pilots to focus only on the most pertinent information (Ison, 2016). A glass cockpit is the core of the Technologically Advanced Aircraft (TAA) which is a modern term used to describe light aircraft with advanced equipment on board, specifically advanced avionics like GPS and glass panel displays.

Glass cockpit displays rely on computerized systems that integrate multiple data inputs and controls. Glass cockpit displays can present more information in the space required for conventional instrument panels, but the increase in information places greater demands on pilot's attention and creates a risk of overloading pilots with more information than they can effectively monitor and process. The complexity of the integrated computerized systems that drive glass cockpit displays may also limit pilots' understanding of the functionality of the underlying systems (National Transportation Safety Board, 2010).

The analysis of both the cockpit layouts and their benefits and disadvantages points out to a few facts (Vlacic et al, 2014):

− The information in a digital glass cockpit is more precise and, due to computer screens, can be displayed much more ergonomically;

− Glass cockpits have a tremendous amount of information available to pilots, which is not available from cockpits with analog gauges;

− Disadvantages of traditional analog instrumentation are the multitudes of mechanical components so glass cockpits also provide an element of maintenance simplicity;

− Analog gauges can be more easily interpreted during rapid changes in airspeed and altitude;
− Pilots with glass panels may also be spending more time looking at the displays instead of looking outside;
− In case of turbulence and emergencies, pilots using glass cockpits may touch and activate wrong buttons because there are so many of them in a small area;
− Flying a glass cockpit aircraft requires a different cognitive style of thinking.

It can be concluded that if we want to attain a desired level for safe flying with a glass cockpit, ground training with the use of synthetic devices is also necessary. The process of re-training pilots trained in traditional analog cockpits will not be so easy and fast and it takes time which has to be determined in the next phase of acquiring the Lasta fleet. Because of the cockpit complexity and our study program curriculum timeline, it will be impossible to use the Lasta in the process of selecting future pilots in the primary flight training phase.

In today's fully integrated cockpit, learning how to use these new tools effectively, while still maintaining the control of the aircraft, is something that will keep the training squadron busy for years to come. For pilots who are going to be converted to a glass cockpit and want to gain numerous advantages of modern avionics, there are a number of training options. Many suppliers provide Internet-downloaded trainers free of charge, and there are free online interactive courses. Commercial DVDs and training simulators are extremely useful, too. However, realistic flight training using the specific system in busy airspace during less-than-ideal weather with an experienced flight instructor is a must. (Decker, 2013)

Also, manufacturers of the before mentioned equipment provide only a small part of educational software (for each device separately), but such educational software is not tailored to the specific layout of Lasta's cockpit (Vlačić, 2011).

Digital training

It is important to understand the difference between learning and training. They are inextricably linked, but they are unique aspects of any educational process. Training is the giving of information and knowledge, through speech, the written word or other methods of demonstration in a manner that instructs the trainee. Learning is the process of absorbing

that information in order to increase skills and abilities and make use of it under a variety of contexts.

The quality of learning will rely largely on the quality of training.

Training focuses more on the development of new skills or skill sets that will be used. Training is the process each new trainee (cadet) goes through when joining a flight squadron to learn how to carry out day-to-day operations, know how their airplane works and how job-specific tools operate in order to carry out their responsibilities. In essence, through training, the goal is not to reshape the behavior of an individual rather the point is to teach the cadet how things are done so that they can then carry out a process on their own.

Digitalization is today an inevitable part of any learning or training proccess, especially in modern aviation. There are many definitions of what digital learning is, but a clear definition of digital training is lacking.

Digital learning is "learning facilitated by technology that gives students some element of control over time, place, path and/or pace" (GOSA, 2021). Also, digital learning is any type of learning that is accompanied by technology or by instructional practice that makes effective use of technology. Digital technologies are electronic tools, systems, devices and resources that generate, store or process data (Victoria State Government, 2021). Digital learning is sometimes confused with online learning or e-learning; digital learning encompasses the aforementioned concepts. Digital learning requires a combination of technology, digital content, and instruction.

Technology is the mechanism that delivers content. It facilitates how students receive content. It includes Internet access and hardware, which can be any Internet access device – from a desktop to a laptop to an iPad to a smartphone. Technology is the tool, not the instruction.

Digital content is the high-quality academic material delivered through technology. It is what students learn. It ranges from new engaging, interactive and adaptive software to classic literature, from video lectures to games. It is not simply a PDF file of a text or a PowerPoint presentation.

However, there is no distinctive definition of digital training. Some sources indicate that it is an evolution of e-learning that uses the Internet to make online training courses. Computers, tablets, mobiles or even connected objects, are all means to easily access this type of training. Nevertheless, digital training has much broader contest.

For the purpose of this paper, we consider digital training to be training which includes a variety of digital devices in order to improve the

quality of flight training, having in mind the previously mentioned differences between learning and training.

Implementation of the digital training concept

Aircraft manufacturers usually deliver training aircraft to the end user with a wide spectrum of additional training devices (Vlačić et al, 2015), but the developer of the Lasta has not provided training devices and simulators yet. The Military Academy staff had to develop or procure the whole spectrum of training devices in order to make the training process more effective. These devices are part of the set that makes up the concept of digital training on the Lasta airplane. In the meantime, cockpit digitalization has become reality in a few new acquisitions, including the Airbus H-145M utility helicopter or the Mi-35M combat helicopter. In this way, acquisition and equipment with adequate devices for pilot training become a necessity and one of the priorities in aviation modernization (Vlačić et al, 2015).

The main changes in the flight training process occured due to new airplanes equipped with modern hardware and software in different domains. This is most obvious in the aircraft cockpit layout. The main goal of their incorporation was a higher level of flight safety, better efficiency of training and, most importantly, higher combat efficiency of the airplane as a platform. Higher demands placed in front of trainees were somewhat compensated with a wide use of flight trainers/simulators and other digital training devices. Their use in modern training is inevitable. For many years, training devices were developed and produced exclusively by original manufacturers. This led to high prices, caused by industrial monopoly and the application of rigid industrial and military standards. Remarkable development of hardware and software has made these items more affordable than ever if price and performances are considered. This fact opened the door for less specialized personnel to create and develop some training devices. The great change was also made by wide recognition and involvement of Commercial off-the-shelf (COTS) components in the process of creating systems for military use. These facts enabled less experienced staff to create their own digital devices and their own approach to the creation of the digital training concept.

The focus of the use of digital devices has been placed on basic training. The nature of basic flight training requires not only acquiring basic knowledge and skills but a student in training also has to "to learn how to learn". "Inserting" a student-pilot in a real cockpit without

introduction and adaptation to digital devices reduces the effectiveness of training in many ways.

In creating the concept, the ways of training by which the greatest success is achieved are taken into account. Regardless of different scientific views (Kåre & Sigbjørn, 2018), it is undeniable that a high level of adaptation of knowledge and skills is achieved through one's own practice and repetition of actions and procedures, instead of simply listening and watching.

Digital training has to be divided in several levels in accordance with training objectives i.e. what specific and useful knowledge, skills, and techniques have to be developed in certain phases of training.

The digital concept in basic flight training contains several levels including:

Interactive learning materials;
Flight Simulator based on commercial software;
Virtual reality (VR) devices;
Learning Management System (LMS);and
Other training hardware and software.

Interactive learning materials

Today there is a broad range of interactive learning materials which provide cadets - pilots with the aviation knowledge they require to prepare for theoretical examinations and to become safe and competent pilots. After evaluation, the Military Academy opted for the CAE Oxford Aviation Academy interactive materials in compliance with the EASA[1] standards. These materials have the form of full color textbooks and multimedia computer-based training (CBT), both comprehensively covering the theory but delivering it in a different way.

Within CBT, each lesson is accompanied by clear precise narration which leads students through each essential teaching point. The lessons are built with an effective combination of graphics, animations, audio voice-overs, textual key-points and revision questions, providing a unique and effective way of mastering difficult concepts in an engaging way.

During the six years of CBT application, cadets demonstrated better results[2] in subjects in which CBT were used. The comprehensible manner gave cadets a lot of good examples and advice on how to deal with problems in future flight training.

[1] EASA – European Aviation Safety Agency
[2] according to the Military Academy evaluation process

Also, embedding new cockpit instruments imposed new training approaches. Because of the Garmin origin, the Military Academy introduced the dedicated Garmin software and hardware simulator for its complex devices such as Garmin G500/600. The basic variants of this simulator can be viewed and downloaded at the Garmin support pages (Garmin, 2021). This simulator allows cadets to perform basic functions within the Garmin system. It is possible to learn how to input data and frequencies using tips and tricks for “best practices”. Cadets learn to navigate using flight plans and GPS direct courses. They are able to navigate pages and page groups of the Flight Management System, while recognizing the most important functions using tips and tricks. The first generation of cadet pilots who started their flight training after practicing on this simulator shows better performance in the basic stages of the flight syllabus.

LMS in the flight training preparation phase

The Military Academy staff has decided to implement MOODLE e-learning platform in the Military Aviation study program (http://adl.elearning.mod.gov.rs/). MOODLE (Modular Object-Oriented Dynamic Learning Environment) is a free source e-learning system shell (LMS), written in PHP. It is an important tool for e-learning and blended learning which provides a framework for preparing courses and for learning over it. Various content is provided over this system shell (texts, pictures, optional files, links, multimedia etc.), but the tasks related to them that can be scored are also important (assigning tasks in the form of online texts, file, varied types of tests, offline tasks, etc.). This system unifies and presents, in a single surface, all the services that are otherwise applied by teachers on parallel surfaces, often offline (sharing documents and information, sending messages, evaluation, etc.) (Namestovski & Arsovic, 2013).

Microsoft Flight Simulators

Microsoft Flight Simulator X, also known as FSX, is a 2006 flight simulation computer game originally developed and published by Microsoft for Microsoft Windows. It is the next in the sequence after Microsoft Flight Simulator 2004. This software can be classified as virtual modeling on a computer workstation. One of the enduring problems with any flight simulator is a restricted field of view (FOV) imposed by the computer display screen. This restriction severely limits peripheral vision, which in turn detracts from perceived realism.

The external graphic card Matrox TripleHead2Go expanded Flight Simulator X across three displays (Figure 3), providing a panoramic view that enables users to see more of their virtual cockpit and improves flight visibility at the same time. This extended view provides a more realistic flight experience by fully engaging peripheral vision on the side displays.

As a further level, Microsoft Flight Simulator 2020 was introduced in order to support FSX. Microsoft Flight Simulator 2020 was released in 2020, for Microsoft Windows, with a virtual reality (VR) version. Flight Simulator simulates the topography of the entire Earth using data from Bing Maps. Artificial intelligence (AI) generates three-dimensional representations of Earth's features, using its cloud computing to render and enhance visuals, and real-world data to generate real-time weather and its effects. Flight Simulator has a physics engine to provide realistic flight control surfaces, with over 1,000 simulated surfaces, as well as realistic wind modelled over hills and mountains. Some places are handcrafted, introduced in region-specific updates. To augment its realism, AI also incorporates real-time elements like natural weather and real-world air traffic. The gameplay includes new features such as landing challenges and helpers.

Figure 3 – Expanding FSX across three displays
Рис. 3 – Расширение изображения программы авиасимулятора на трех дисплеях
Слика 3 – Проширење приказа програма симулатора летења на три приказивача

The developer scanned the interiors and exteriors of aircraft with a 3D scanner to create their realistic looks, polished with modeling and printing (Aysha, 2020). There are also realistic physics and weather systems, and utilization of real-world weather data. For instance, if it is raining somewhere in real life, it can rain in-game. Individual clouds have their own behaviors and will impact aircraft performance depending on its location within the system. Flight Simulator is the first flight simulator to enable worldwide visual flight rules (VFR), a feature not seen in contemporary flight simulators used by airlines to train and test pilots.

Through cloud-based technology, Flight Simulator sends data to the computer in real time, with AI being utilized to extrapolate geometry from a blend of satellite and flyover imagery (Jensen, 2020). Other sources of data include terrain data for landscaping, data for foliage density, real-time meteorological data, and air traffic updates. Cloud technology is used to calculate, among other things, the way air flows around natural structures such as mountains to cause pockets of turbulence, or streams in the world's real-time air traffic, and time of day and weather.

Microsoft simulators are mainly used to demonstrate cockpit views and basic systems characteristics in the aircraft used in real flight training. To simulate domestic airplanes (UTVA-75, Lasta, Supergaleb G-4) which are not involved in the FSX package, the specific add-ons have been created as a long-term process. Developing one’s own add-ons was the first step in creating a basic flight simulator. However, it is important to stress that during the flight-training phase in military jets (G-4 Supergaleb in our case) a full-scale flight simulator is used. The use of a full flight simulator is expensive and impracticable in the basic training phase, which is our point of consideration.

When speaking about the assessment and worthiness of the kind of software such as Microsoft simulators, we have to mention what kinds of simulators and simulations exist on the market. Simulations can consist of virtual modeling on a computer workstation, part task devices with actual system hardware and software, or full-mission man-in-the-loop simulators with visual systems and motion. All have their place in the process, and all play a role in shortening development time and cost (Vlačić, 2011).

Both versions of Microsoft Flight Simulators have been procured for the training process in the Military Academy. The main advantages are not only visual simulation but the possibility to connect many modern peripherals such as virtual reality and eye tracking devices.

VR devices

Virtual reality (VR) has been developed to facilitate human immersion into new computer-generated synthetic environments that block out the real world. Recent advancements in VR technologies enable users to interact with high resolution three-dimensional graphics without any significant video delay. This technological advancement for VR systems has reinforced its professional training applications, including those for aircraft pilots. Conventional flight simulator systems can generate realistic situational conditions, installing out-the-window scenery screens in front of their mockup cockpits with motion platforms, but the setting at such a level, which is costly and requires a 360° angle of-scenery screen, is still hard to implement. VR has the advantage of implementing the 360° angle-of horizontal - and vertical-scenery view for a lower cost.

Pilots are exposed to a lot of safety-critical situations, and they have to practice recovery skills against all potentially dangerous situations. VR can show a better performance for this kind of dangerous situation training than conventional simulators due to its higher realism. Pilots also have to develop skills to manipulate modern electronic cockpit systems, including setting the objective heading direction on the electronic compass, magnifying/demagnifying the electronic map display, and switching communication radio frequencies with other channels. The high-cost conventional mockup simulators install the actual electronic cockpit hardware, for which all functionalities can be manipulated by manual controls (Chang-Geun, 2020).

The main benefit of virtual reality in flight training is the immersive representation of the flight experience, providing some important learning advantages over traditional flight simulators. The key benefits for flight schools include reduced training costs, cost savings on aircraft familiarization training, and faster training of students.

Virtual Reality (VR) is the concept of being immersed into a computer-generated environment with a visual, audible and optionally haptical representation of the environment. This environment, e.g. a room, landscape or a cockpit, may be presented to the user through a screen or a head mounted display (headset). The user may be able to interact with the environment, e.g. through gestures or physical buttons or levers.

VR offers new opportunities for significant improvement of teaching and learning as subjects can be taught/learnt in a very different way instead of reading a textbook or listening to a lecturer.

One of the most important aspects of learning is knowledge retention – the ability to remember what has been learnt. This is especially true for flight crews who must memorize dozens of checklists, rules, and procedures. Studies have shown that VR-assisted learning has the potential of improving knowledge retention by up to 400%, adding value to the time spent studying. Better knowledge retention means less retraining and, in the end, better pilots who remember the emergency checklist better thanks to VR-assisted learning.

VR engages the student much more in the learning process, thus making the student remember more of what he or she learns. This is an obvious advantage when performing tasks as a flight crew where complex procedures must be memorized.

Studies have shown a dramatic reduction in training time when using VR simulations – for flight training application as much as one year down to four months. Some benefits that provide training time reduction are depth perception, 360° vision, scalability, and modularity (VRpilot, 2021).

The Military Academy uses the Oculus Rift VR device which is one of typical representatives in this device category (Figure 4).

Figure 4 – Oculus Rift VR in basic flight training
Рис. 4 – Oculus Rift VR в основной летной подготовке
Слика 4 – Oculus Rift VR у основној летачкој обуци

The Oculus Rift VR headset uses gaze tracking and IR LED sensors to identify the user's position and, at the same time, to interact with the virtual environment. Users can move freely within their physical environment - sit, stand, walk, turn, duck, and dodge as they desire. Similarly, it is possible to simulate the aerial environment as well as the image of the aircraft cockpit. A VR headset enables a stereo image of the pilots' workspace and gaze sweeping inside and outside the cockpit. The headset has an OLED display with 2060 X 1200 resolution and a 90Hz refresh rate. The field of view (FOV) is 110 º and the tracking area is 12.7 by 27.94 cm'. The sensors include accelerometers, gyroscopes, and magnetometers. The system enables full 360-degree positional tracking.

Other training hardware and software

The commercial flight simulator created in the Military Academy provides connection for many other devices that can be used in cadets' training and evaluation. The most important is the GP3 Desktop Eye Tracker device.

In nearly all human-computer interactions, the most basic point of connection between an interface and its user is the eye. Eye tracking has been an important source of information about perception and cognition for more than 50 years. It has been utilized to study a diverse number of topics such as the patterns of fixations and saccades while reading a text, the workload of pilots during different phases of flight, the application of different scan patterns in flight training, the role of pilots' monitoring strategies in flight performance and the effectiveness of visual advertisements among many others. In the Military Academy case, pilot's eye movement patterns are recorded by using the GP3 Desktop Eye Tracker. The GP3 Desktop Eye Tracker is a complete eye tracking system used as a device for measuring eye positions and eye movement.

The role of the GP3 Desktop Eye Tracker is to make assessment during flight simulation. The assessment is done regarding the senses and skills necessary for flying as well as piloting skills in the air. The Piloting techniques are assessed in the air according to standard practices for monitoring, assessment, and evaluation.

Assessment helps cadets to improve their ability to successfully cope with the flight syllabus and develop the required pilot aptitudes.

The biggest contribution of this kind of equipment is in improving the pilot selection process using eye tracking tools (Vlačić et al, 2019).

The Sky Demon is one of numerous electronic flight bag software programs available on the market. It enables flight planning as well as

GPS navigation in the air. Its special features include real-time updates of aeronautical information. For navigation training purposes only, the internal simulation software, called the X-plane, enables the simulation of the flight along the planned route. Furthermore, it is possible to connect the Sky Demon in the simulation mode with Microsoft Flight Simulator via the FSX2SkyDemon application available on the Google Play Store. This small application receives the data from the FSX software and presents the information about the aircraft performance and position in the form of a track plot on top of the Google Earth maps. At the same time, it forwards the data to the Sky Demon software and makes it look like the user is flying a real airplane. Real-time aeronautical information from the Sky Demon, especially the information about the wind has a feedback impact on the aircraft performance in FSX.

For navigation training, the Sky Demon software installed on a tablet is connected with Microsoft Flight Simulators (Figure 5).

Figure 5 – Connection of the Sky Demon tablet with Microsoft Flight Simulators
Рис. 5 – Подсоединение планшета с программой Sky Demon к авиасимулятору Microsoft Flight Simulators
Слика 5 – Повезивање таблета који поседује програм Sky Demon са програмом Microsoft Flight Simulator

Diversity and fine balance of devices used in the showed digital concept provided a step forward into better basic flight training. According to internal documents, there were no failures in basic flight training after the implementation of the digital training concept.

Conclusion

Basic flight training is considered as the most important phase of flight training and a core of a successful process of making future military pilots. This training phase has experienced significant changes with the introduction of the Lasta piston engine trainer which belongs to the Technically Advanced Aircraft category. This aircraft is characterized by a high degree of cockpit digitalization and aircraft systems as a whole. The technical level of the Lasta aircraft equipment requires a great effort towards achieving a required level of confidence and safe operation. In order to attain a desired level of safe flying with a glass cockpit, ground training with the use of digital synthetic devices is also necessary.

The developer of the Lasta has not provided training devices and simulators yet. The Military Academy staff developed and procured a whole spectrum of training devices in order to make the training process more effective. Digital training as a type of training includes a variety of digital devices in order to improve the quality of flight training. In the case of basic flight training in the Military Academy, the digital concept of training consists of:

Interactive learning materials;
Flight Simulator based on commercial software;
VR devices;
LMS; and
Other training hardware and software.

The first generation of cadets - pilots who started their flight training after practicing on this simulator shows a better performance in the basic stages of the flight syllabus. The COTS based simulator was the core for other peripherals.

VR offered new opportunities to significantly enhance the flight training process. Cadets learn faster and more efficiently while remembering the lessons taught better.

The GP3 Desktop Eye Tracker has proved to be an assessment tool during the simulated flight training. Assessment is done regarding the senses and skills necessary for flying and piloting skills in the air. The biggest contribution of this kind of equipment is in the improvement of the pilot selection process using eye tracking tools.

Despite the fact that the digital training concept is not mandatory in the existing flight training model in the Serbian Military Academy, it proves valuable. Its potential is considerable, and, to a certain extent, it can change the nature of basic flight training. Due to the digital training concept, cadets can fly more safely and their flying skills are acquired faster.

References

Aysha, M. 2020. Microsoft Flight Simulator made more realistic thanks to 3D scanning. *3Dnatives*, 27 October [online]. Available at: https://www.3dnatives.com/en/microsoft-flight-simulator-271020205/# [Accessed: 20 October 2021].

Chang-Geun, O. 2020. Pros and Cons of A VR-based Flight Training Simulator; Empirical Evaluations by Student and Instructor Pilots. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting,* 64(1), pp.193-197. Available at: https://doi.org/10.1177/1071181320641047.

Decker, T. 2013. Glass Cockpit Flight Training. *Aviator college's Blog*, 10 April [online]. Available at: http://aviatorcollege.wordpress.com/2013/04/10/glass-cockpit-flight-training/ [Accessed: 7 July 2021].

-Garmin. 2021. *G500/G600 Series Trainer Base Install software version 1.2.0* [online]. Available at: http://www8.garmin.com/support/download_details.jsp?id=4867 [Accessed 15 October 2021].

-GOSA (The Governor's Office of Student Achievement). 2021. *What is Digital Learning?* [online]. Available at: https://gosa.georgia.gov/about-us/what-digital-learning [Accesed 28 September 2021].

Ison, D. 2016. Is Glass Safer? *Plane & Pilot*, 6 February [online]. Available at: https://www.planeandpilotmag.com/article/is-glass-safer/ [Accessed: 20 October 2021].

Jensen, K.T. 2020. Why Microsoft Flight Simulator 2020 Is This Year's Most Ambitious Game. *PCMag*, 18 August [online]. Available at: https://sea.pcmag.com/computer-console-gaming/38658/why-microsoft-flight-simulator-2020-is-this-years-most-ambitious-game [Accessed: 20 October 2021].

Kåre, L. & Sigbjørn, H. 2018. Excavating the origins of the learning pyramid myths. *Cogent Education,* (5)1, pp.1-17. Available at: https://doi.org/10.1080/2331186X.2018.1518638.

Namestovski, Z. & Arsovic, B. 2013. Possibilities of implementing web 2.0 tools in education. In: *International Conference on Information Technology and Development of Education – ITRO 2013*, *Proceedings,* Zrenjanin, pp.43-45, June [online]. Available at: http://www.tfzr.rs/itro/Zbornik2013.pdf [Accessed: 20 October 2021].

-National Transportation Safety Board. 2010. *Introduction of Glass Cockpit Avionics into Light Aircraft*, *Safety Study* [online]. Available at: https://www.ntsb.gov/safety/safety-studies/Documents/SS1001.pdf [Accessed: 20 October 2021].

-Victoria State Government. 2021. *Teach with digital technologies* [online]. Available at: https://www.education.vic.gov.au/school/teachers/teachingresources/digital/Pages/teach.aspx#:~:text=Digital%20technologies%20are%20electronic%20tools,across%20all%20curriculum%20learning%20areas [Accesed: 28 September 2021].

Vlacic, S., Rodjenkov-Milinkovic, S., Knezević, A. & Vlacic, I. 2014. Use of the commercial software tools in the preparation phase of military pilot education and training. In: *International Conference on Information Technology and Development of Education – ITRO 2014, Proceedings*, Zrenjanin, pp.346-350, June [online]. Available at: http://www.tfzr.rs/itro/Zbornik_ITRO_2014.pdf [Accessed: 20 October 2021].

Vlačić, S. 2011. Training devices and flight simulators variants of application in pilots training on the aircraft Lasta. In: *4th International scientific conference on defensive technologies OTEH 2011*, Belgrade, pp.143-146, October 6-7 [online]. Available at: http://www.vti.mod.gov.rs/oteh11/index.htm [Accessed: 20 October 2021].

Vlačić, S.I., Knežević, A.Z., Mandal, S., Rođenkov, S. & Vitsas, P. 2019. Improving the pilot selection process by using eye-tracking tools. *Journal of Eye Movement Research,* 12(3). Available at: https://doi.org/10.16910/jemr.12.3.4.

Vlačić, S., Knežević, A. & Milutinović, M. 2015. Application of commercial available hardware in the making of flight trainer *International Conference on Information Technology and Development of Education – ITRO 2015, Proceedings,* Zrenjanin, pp.284-289, June [online]. Available at: http://www.tfzr.rs/itro/Zbornik%20ITRO%202015.pdf [Accessed: 20 October 2021].

-VRpilot. 2021. *Virtual Reality & Flight Training* [online]. Available at: https://vrpilot.aero/virtual-reality-flight-training/ [Accessed: 17 October 2021].

ВНЕДРЕНИЕ КОНЦЕПЦИИ ЭЛЕКТРОННОГО ОБУЧЕНИЯ В ПРОГРАММУ ОСНОВНОЙ ЛЕТНОЙ ПОДГОТОВКИ В ВОЕННОЙ АКАДЕМИИ РЕСПУБЛИКИ СЕРБИЯ

Славиша И. Влачич[а], **корреспондент**, *Александар* З. Кнежевич[а], *Владимир* М. Грбович[б], *Панос* А. Витсас[в], *Михайло (Майк)* С. Михайлович[г]

[а] Университет обороны в г. Белград, Военная академия, Кафедра военной авиации, г. Белград, Республика Сербия

[б] Вооружённые Силы Республики Сербия, Военно-воздушные силы и Противовоздушная оборона (ВВС и ПВО), г. Белград, Республика Сербия

[в] Международная школа летчиков-испытателей, г. Лондон (Онтарио), Канада

[г] Правительство Онтарио, г. Торонто, Канада; MRTD Defense Eng, г. Торонто, Канада

РУБРИКА ГРНТИ: 78.00.00 ВОЕННОЕ ДЕЛО:
78.25.13 Военная авиационная техника и вооружение,
78.21.49 Военная электроника и кибернетика
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: В статье представлен обзор последних исследований в области концепции электронного обучения, применяемой в летной подготовке в Военной академии Республики Сербия. Летная подготовка является залогом успешного обучения военных летчиков. Она подразделяется на этап освоения окружения и этап реализации. Главной частью и ядром успешной летной подготовки является основная летная подготовка. Этот этап обучения потерпел значительные изменения, вследствие внедрения технически усовершенствованных самолетов (ТАА), для которых характерна высокая степень цифровизации не только стеклянной кабины, но и системы самолета в целом. В данной связи, необходим иной методологический подход к обучению, включающий концепцию электронного обучения. В статье представлен ряд достижений и решений, используемых в основной летной подготовке в Военной академии Республики Сербия, с применением элементов концепции электронного обучения.

Методы: Используя научный подход, был проведен анализ цифровизации стеклянной кабины самолета и результатов внедрения новой концепции обучения в основную летную подготовку в Военной академии Республики Сербия.

Результаты: На основании проведенного методологического анализа выявлены значение и ценность концепции электронного обучения в рамках основной летной подготовки.

Выводы: Вопреки тому, что концепция электронной подготовки не является обязательной частью существующей модели летной подготовки в Военной академии Республики Сербия, она является весьма значительной и ценной. Ее потенциал настолько значителен, что в определенной степени, может изменить характер основной летной подготовки. Концепция электронного обучения способствует безопасности курсантов в будущих полетах, а также ускорению процесса приобретения летных навыков. В связи с приобретением новых современных самолетов ВВС и ПВО Республики Сербия, каждый аспект концепции электронной подготовки должен быть тщательно рассмотрен, особенно на этапе основной летной подготовки, включая этап перехода к новым типам самолетов.

Ключевые слова: летная подготовка, стеклянная кабина, электронное обучение, учебные средства.

ПРИМЕНА КОНЦЕПТА ДИГИТАЛНЕ ОБУКЕ У ОСНОВНОЈ ЛЕТАЧКОЈ ОБУЦИ НА ВОЈНОЈ АКАДЕМИЈИ

Славиша И. Влачић[а], **аутор за преписку**, *Александар* З. Кнежевић[а], *Владимир* М. Грбовић[б], *Панос* А. Витсас[в], *Михајло (Мајк)* С. Михајловић[г]

[а] Универзитет одбране у Београду, Војна академија, Катедра војног ваздухопловства, Београд, Република Србија

[б] Војска Србије, Ратно ваздухопловство и противваздухопловна одбрана, Београд, Република Србија

[в] Међународна школа за опитне пилоте, Лондон (Онтарио), Канада

[г] Влада Онтарија, Торонто (Онтарио), Канада; MRTD Defense Eng, Торонто (Онтарио), Канада

ОБЛАСТ: ваздухопловство, информационе технологије
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: У раду су представљена недавна истраживања у области концепта дигиталне обуке примењеног у летачкој обуци на Војној академији Републике Србије, која чини основу успешног образовања војних пилота. Њена подела заснована је на окружењу и фази реализације. Главни део и основу успешне летачке обуке представља основна летачка обука. Ова фаза обуке доживела је значајне промене увођењем технички напредних авиона (ТАА) који се одликују високим степеном дигитализације кабинског простора и система авиона у целини. Сходно томе, потребан је другачији методолошки приступ обуци, укључујући концепт дигиталне обуке. Приказана су достигнућа и поједина решења која се користе у основној летачкој обуци на Војној академији, уз примену елемената дигиталних концепата обуке.

Методе: Користећи научни приступ извршен је увид у дигитализацију пилотских кабинских простора и имплементације новог концепта у основну летачку обуку на Војној академији Републике Србије.

Резултати: На основу примењене методе анализе приказани су значај и вредности концепта дигиталне обуке у основној летачкој обуци.

Закључак: Иако концепт дигиталне обуке није обавезан у постојећем моделу летачке обуке на Војној академији Србије, показало се да је веома значајан. Његов потенцијал је велики и, до одређеног нивоа, може променити карактер основне летачке обуке. Захваљујући концепту дигиталне обуке, кадети касније могу безбедније управљати летелицама и брже стицати летачке вештине. У складу са набавком нових савремених авиона у Ратном ваздухопловству и противваздухопловној одбрани Војске Србије,

сваки аспект концепта дигиталне обуке мора се пажљиво размотрити, посебно у фази основне летачке обуке, укључујући и фазе преласка на нове типове авиона.

Кључне речи: летачка обука, стаклени кабински простор, дигитална обука, средства за обуку.

Paper received on / Дата получения работы / Датум пријема чланка: 26.10.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 03.01.2022.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 04.01.2022.

LOGISTICS SUPPORT PLANNING MODEL IN THE CONDITIONS OF LIMITED RESOURCES

Nikola B. Simić[a], *Marjan* A. Milenkov[b], *Vladimir* R. Milovanović[c], *Vlada* S. Sokolović[d], *Pavel J.* Foltin[e], *Balázs J.* Taksás[f]

[a] University of Defence in Belgrade, Military Academy, Department for Logistics, Belgrade, Republic of Serbia, e-mail: nikolasimicva@hotmail.com, ORCID iD: https://orcid.org/0000-0002-0561-6555

[b] University of Defence in Belgrade, Military Academy, Department for Logistics, Belgrade, Republic of Serbia, e-mail: marjan.milenkov@va.mod.gov.rs, ORCID iD: https://orcid.org/0000-0003-2054-0525

[c] University of Defence in Belgrade, Military Academy, Department for Logistics, Belgrade, Republic of Serbia, e-mail: vaci84milovanovic@gmail.com, ORCID iD: https://orcid.org/0000-0002-6787-4058

[d] University of Defence in Belgrade, Military Academy, Department for Logistics, Belgrade, Republic of Serbia, e-mail: vlada.sokolovic@va.mod.gov.rs, **corresponding author,** ORCID iD: https://orcid.org/0000-0003-0782-0506

[e] University of Defence in Brno, Faculty of Military Leadership, Department of Logistics, Brno, Czech Republic, e-mail: pavel.foltin@unob.cz, ORCID iD: https://orcid.org/0000-0001-8270-0390

[f] University of Public Service, Faculty of Military Science and Officer Training, Department of Supply, Finance and Military Transportation, Budapest, Hungary, e-mail: taksas.balazs@uni-nke.hu, ORCID iD: https://orcid.org/0000-0001-7583-4198

DOI: 10.5937/vojtehg70-33079; https://doi.org/10.5937/vojtehg70-33079

FIELD: Logistics, Engineering management, Information technology
ARTICLE TYPE: Original scientific paper

ACKNOWLEDGMENT: The work stemmed from the Model of Logistics Support Planning Support System (VA-TT-1 / 20-22) Project, Military Academy, University of Defense in Belgrade.

Abstract:

Introduction/purpose: The paper presents a model of logistics support planning in the conditions of limited logistic resources based on the prioritization of customer requirements and resource allocation. Decision-makers play a crucial role in the efficient and equitable allocation of resources as they prioritize among different user requirements.

Methods: Requirement prioritization techniques that use nominal scale, ordinal scale, and ratio scale, and five methods for converting ranks into weighting coefficients have been applied to determine the degree of significance of user requirements. The Requirements triage method has been used for establishing relative priorities, while the heuristic algorithm determining the Kemeny median was used *to consolidate individually ranked requests into a group rank. In order to balance opposing demands of users, consensus measures of group decision making were used. For obtaining an optimal planned solution of logistic support, the methods and techniques of resource allocation were applied.*

Results: A model for adaptive planning of logistics support in the conditions of limited resource capacities of the logistics system has been developed.

Conclusion: The proposed model can be effectively applied in other areas of resource allocation.

Keywords: logistics planning, requirement prioritization, triage, converting ranks into weights, resource allocation.

Introduction

Logistics support planning is a highly complex problem in a military organization. Research shows that even the most powerful armies in the world face numerous issues in planning the logistic support of military operations (McConnell & King, 2019). The most common problems faced by military logisticians are difficulties in forecasting, lengthy work, mismatch of requirements, and poor visibility of logistic resources.

It is generally known that many logistics aspects (user requirements, resource capacities, operational environment, time, etc.) are stochastic, dynamic, and nonlinear, which causes high sensitivity of the logistic system (Milenkov et al, 2020).

For military units to maintain the combat strength needed to conduct operations in the new environment, whether combat or humanitarian, research shows that armies will need to fundamentally improve their logistics models used in the previous period and conduct extensive logistics planning (Hurley & Coleman, 2018).

During the logistics support planning process, logistics bodies have an essential role, first to understand and then to balance opposing requirements of users, and with their knowledge, competence, and ability to create an optimal Logistics Support Plan which will, in the observed planning period, ensure the best overall military organization performance with a limited resource capacity of the logistic system (Jia et al, 2020).

All these limitations motivated the authors to explore the possibility of applying the allocation of limited resources to the existing logistics system and develop an awareness of the need to modernize the way of thinking, decision making, and reducing the stress of logistics organs due to increased outflow of staff.

Whenever deadlines are short, resources are limited and user requirements exceed the resource capacities of the logistic system, it implies that some requirements would not be completely met. In that case, it is necessary to decide which requirements will be fully completed, which partially, and which will not be completed, i.e. it is essential to prioritize the requirements and allocate resources with which the conflicting user requirements will be met to a certain extent. Accordingly, priority prioritization and resource allocation are significant activities in logistics support planning.

Determining the needs for ammunition (Zlatnik & Mares, 2020), fuel, spare parts, food and water items, determining the occurrence of failure on assets, as well as the place and time of service procedures, requires extensive calculations and forecasts. To take specific measures to meet these needs, logistics authorities must gain direct insight into the state of availability of resource capacities of the logistics network (no matter whether it is material stocks or maintenance capacities). These problems cannot be adequately solved without modern decision support tools that can predict rapid changes in logistic requirements and analyze the resource capacities of the logistic network (McConnell et al, 2021). Some of these tools, which can be found in the literature, belong to MCDM methods: MARCOS, CODAS, EDAS, VIKOR, MABAC, and many others (Li et al, 2020).

MARCOS (Measurement of Alternatives and Ranking according to COmpromise Solution) considers an anti-ideal and ideal solution at the very beginning of the formation of an initial matrix, closer determination of utility degree concerning solutions, a proposal of a new way to determine utility functions, a possibility to consider a large set of criteria and alternatives while maintaining the stability of the method (Sarma et al, 2020).

CODAS stands for COmbinative Distance-based Assessment, and it is used to determine the desirability of an alternative. This method uses the Euclidean distance as the primary and the Taxicab (non-Euclidean) distance as the secondary measure, and these distances are calculated according to the negative-ideal point. The alternative which has greater distances is more desirable in the CODAS method.

The desirability of alternatives in the Evaluation Based on Distance from Average Solution (EDAS) method is determined based on their distances from an average solution. Because the average solution is determined by the arithmetic mean in this method, the EDAS method can be efficient for solving stochastic problems.

VIKOR (Multicriteria Optimization and Compromise Solution in Serbian) solves decision problems with conflicting and noncommensurable (different units) criteria. Assuming that compromise is acceptable for conflict resolution, the decision-maker wants a solution that is closest to the ideal one, and the alternatives are evaluated according to all established criteria. It ranks alternatives and determines the solution named compromise that is closest to the ideal.

The MABAC (multi-attributive border approximation area comparison) model handles the complex and uncertain decision-making issues by computing the distance between each alternative and the bored approximation area (Pamučar & Savin, 2020).

Based on all the above, the goal of this paper primarily indicates the growing need to develop the logistics planning process, and the final transition from traditional thinking to more modern, innovative solutions to keep pace with foreign armies. In practice, this would be reflected in a fast decision-making process using information systems based on modern resource allocation models to reduced logistics staff effort and shorten response time.

The current process of manual logistic support planning requires a high level of resourcefulness, combinatorics, and calculations to perform all the defined tasks with the best possible results. Based on practical experience, the method of allocation of limited resources was applied in this paper as a starting point for the development of a simplified logistics support plan. Certainly, this paper should contribute to the development of logistics support and the planning process in the army in general, given that the existing literature does not recognize this way of solving the allocation of resources (Daoud et al, 2021).

Nowadays, research shows that even in modern armies, logistics planners do not have adequate tools to help them provide quick answers to questions, especially in a time-limited expedition planning environment (Schwartz et al, 2019). Therefore, the development of more intelligent

planning and analytics tools is enabling the military to expand logistics innovations further and improve the efficiency of the logistics system.

Basic features of the logistics support planning

The logistics support planning is a complex undertaking that requires good forecasting, logistics network optimization, and risk analysis in a highly uncertain environment (Rogers et al, 2018).

The goal of the logistics support planning is to determine the optimal logistics resources, as well as the order, manner, and deadlines for performing logistics support tasks and elaboration of measures, based on the elaborated variant of using engaged forces, objective assessment of the situation, and accurate calculations and activities to increase the efficiency of the logistics system, its stability, and vitality.

Logistics support planning is a segment of the operational planning process and represents a very dynamic process with a defined goal that takes place at a specific time. It requires a creative and organized action of the logistics management bodies which is a necessary condition for achieving a certain degree of organization in preparing executive logistic staff and their precise work plan. The action should be harmonized concerning the set goal, time, and space for the execution of tasks.

In the last period, the countenance of modern military operations has changed radically, which has led to a change in the operational environment and the use of military forces. Modern operations are primarily reflected in the increasingly stringent and complex requirements of users in terms of speed, safety, quality, quantity, and diversity of providing the necessary resources. The emerging operational environment is changing rapidly and requires rapid responses, which has led to traditional military planning not offering good enough solutions.

New approaches to military planning should be able to deal with emerging issues by providing solutions that are robust to deviations from ordinary circumstances and be easily adaptable to new information that becomes known during the execution of the plan, thus increasing effectiveness and efficiency in military operations (Zeimpekis et al, 2015).

Traditional planning seeks solutions that require minimal modifications of the plan during the execution phase. Such an approach to initial plan development may require relatively large calculations. On the other hand, agile planning requires quick solutions that allow a plan modification and re-planning to anticipate events and information during the execution phase (Zeimpekis et al, 2015).

The basic elements considered in logistics support planning for a military operation, as complex actions of the project type, are user requirements viewed as activities to be serviced, time, resources, and costs.

Resources are usually of limited capacity, which leads to the fact that user requests for a specific type of resource are more significant than the ability of the logistics system to fully meet all requests in one particular (given, planned) period of time. In that case, the process of planning the allocation of limited resources is very complex because the logistics authorities are faced with the problem of how to provide an effective, efficient and fair way to meet user requirements while obtaining the most significant global utility of the military system.

Implementing an effective policy of planning and resource management in military logistics requires constant monitoring and a comprehensive analysis of the availability of actual and potential logistic resources. This enables the development of an optimal system of resource allocation among interested users, taking into account the introduction of modern technologies and energy savings (Kostiuchenko & Solomon, 2020).

The approaches to solve the problem of the rational allocation of limited logistic resources, in the logistics planning process, depending on the policy of resource adjustment, can be classified as follows:

- To firmly set a deadline, with a known scope and type of requirements and engage resources sufficient to all user requirements to be met. In this case, a cost minimization strategy is applied;
- To find a solution for known available (limited) resources, with a known scope and type of requirements, which will provide a minimum extension of time to provide the necessary resources and meet all user requirements. In this case, a time minimization strategy is applied;
- To select the type and scope of requirements that can be met, to achieve maximum effects, for known available (limited) resources, in a firmly set period of time. In this case, the strategy of maximizing the global utility is applied, i.e. the rule of allocative or Pareto efficiency.

In the process of the logistics support planning, logistics staff should continuously observe, study and analyze user requirements in different ways and from different points of view, and generally have to make many decisions based on individual perception and experimentally chosen criteria, to respond to the requirements as rationally as possible to users

with available resource capacities of the logistics system (Milenkov et al, 2020).

Figure 1 presents a logistics support planning model.

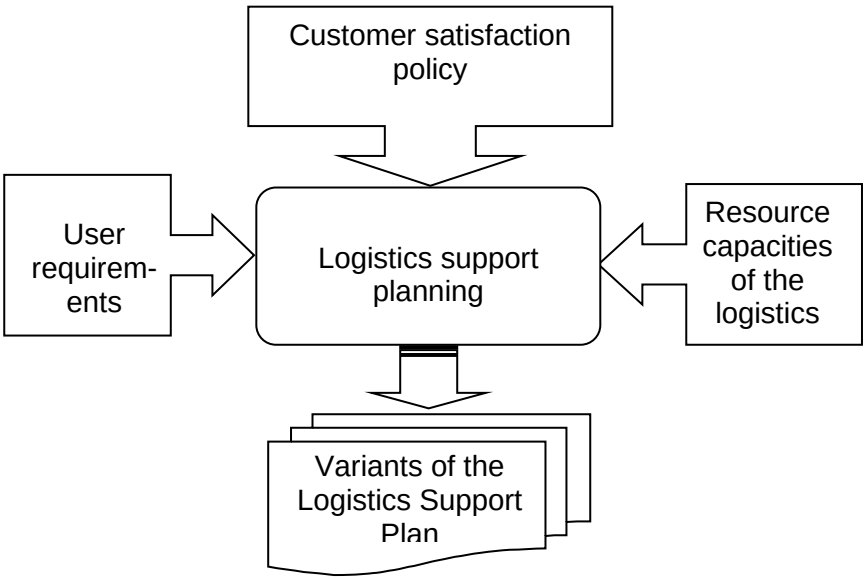


Figure 1 – Logistics support planning model
Рис. 1 – Модель планирования логистической поддержки
Слика 1 – Модел планирања логистичке подршке

The result of the planning process is the Logistics Support Plan, a document in which the planning actions are written towards the set goal. The development of the plan concretizes the goal and determines in more detail what needs to be done to reach the goal, having in mind the probable development of future events. The concretization of the goal includes answers to the questions: what needs to be done, who needs to do it, when it needs to be done, where it needs to be done, with what to do it (with what resources), and how to do it. It aso needs back-up solutions in the case the assumptions and limitations on which the plan change is based (Andrejić et al, 2004; Andrejić, 2001).

The plan must be flexible enough to allow for changes and additions, thus expressing the continuity of the planning process. So, continuity of planning requires reviewing the goals and, if necessary, redefining them, i.e. revising the plan in certain time intervals. In general, the logistics support planning process includes the following steps:

- Determining customer requirements, expressed through the

necessary resource capacities of the logistics system;
- Determining the available resource capacities of the logistics system in the observed planning period;
- Determining the deviation of the required and available resource capacity;
- Choice of policy to meet customer requirements;
- Development of alternative planning solutions;
- Selection of a planning solution from the set of acceptable solutions; and
- Concretization (detailed elaboration) of the selected planning solution.

These activities indicate that in the process of logistics support planning, it is necessary to apply adequate models for the allocation of limited logistic resources in accordance with the conflicting requirements of the users to achieve better global utility of military formation.

It is obvious that solving the problem of allocating limited resources during the logistics support planning process requires the involvement of several stakeholders, which in organizational terms is a collective (group) way of decisions making. Therefore, it is imperative to adhere to certain principles, adopted priorities and present restrictions to mitigate the conflict of the user requirements and make the Logistics Support Plan as efficient as possible.

Logistics support planning based on prioritization of requests and allocation of limited resources

In the broader context of logistics support planning, the first important question that arises is what to allocate and to whom to allocate it, while the second question is how much to allocate. The answers to these questions are very complex and must be assessed against the higher goals of the military organization, especially when there are limited resource capacities of the logistics system. In this regard, the problem of resource allocation is an essential and challenging task in logistics support planning, where logistics resource capacities such as material resources, intangible items (e.g. services), and human resources are allocated in accordance with user requirements.

In general, the problem of resource allocation is present in various fields and attracts the attention of many researchers and practitioners. Different approaches to resource allocation are presented in the literature, which is based on specialized mathematical models and

algorithms (Luss, 2012). These models are used in many areas, such as industrial production management, communication, and computer networks, emergency services, health services, air traffic, allocation of water rights, environmental and military issues (Luss, 2012; Meran et al, 2021; Skobelev, 2011; Hameed et al, 2016).

The central question in resource allocation problems is how to optimize a goal based on certain criteria. In such problems, there are often contradictions and tensions in establishing a certain balance between user requirements because achieving one value can be detrimental to another. These problems are often modelled so that the immediate outcome of optimization is a Pareto set of sustainable solutions (Chevaleyre et al, 2006; Ogryczak et al, 2014).

If there are conflicting goals among interested users, the Pareto set contains several solutions that represent different trade-offs in conflicts over resources. The basic goal of solving such problems is to choose the best compromise for a particular domain in which optimization is applied (Luss, 1999).

Resource allocation is a problem of discrete optimization and belongs to the category of NP-heavy (non-deterministic polynomial-time hardness) problems. Finding solutions that meet all the limitations means searching for a vast space of possible solutions. Therefore, the application of advanced techniques that use different heuristics to narrow the search space allows us to find a solution that is close to optimal.

The development of fully automated systems for solving allocation problems is often rejected in practice. The reason may be restrictions that are difficult to register fully, decision criteria difficult to determine, and end-users not usually being experts in using complex mathematical concepts such as large matrices of mathematical programming or weighting factors of multicriteria optimization.

In the conditions of uncertainty, logistics staff in charge of logistics support planning often have incomplete, inaccurate, contradictory, insufficiently clear, and insufficiently reliable information on user requirements and available resource capacities of the logistics system, which complicates the process of determining the distribution of resources in the logistics system in accordance with customer requirements.

In the case when resource capacities of the logistic system are insufficient to meet all user requirements, specific heuristic rules can provide great assistance to logistics authorities in choosing a policy to meet user requirements, such as:

- Rule "First come, first served";

- Rule "The most urgent request is served first";
- Rule "The request whose realization lasts the shortest is served first";
- Rule "The nearest date is executed first" (request with the shortest time - waiting period);
- Rule "Priority of requests, i.e. ranking of requests according to the degree of significance".

Prioritization of requirements has proven in practice as an effective strategy in the allocation (distribution) of resources that facilitates the decision-making process and allows suppliers to efficiently and fairly provide resources to a larger number of users (Luss, 2012).

Limited resource allocation model

To solve the problem of the logistics support planning, it is necessary to know the requirements of users ($i = 1,2,...,m$) for a particular type of resource (B_{ij}), and, on the other hand, it is necessary to know the availability of required resource capacities of the logistic system (R_j) for the observed planning period.

The value (B_{ij}) represents the needs of the *i*-th user ($i = 1,2,...,m$) for the *j*-th type of resource $(j = 1,2,...,n)$, i.e. $B_j = \sum_{i=1}^{m} B_{ij}$ it represents the total required amount of the *j*-th type of resource of all *m* users. At the same time, the size (R_j) represents the availability of the *j*-th type of resources in the observed planning period.

Satisfaction of specific user requirements with the *j*-th type of available resources (R_j) can be presented as follows:

$$R_j = \sum_{i=1}^{k} R_{ij}^{+} + \sum_{i=k+1}^{l} R_{ij}^{*} + \sum_{i=l+1}^{m} R_{ij}^{-} \qquad (1)$$

where:

R_j^{+} - the amount of the *j*-th type of resource with which it entirely (100%) meets specific user requirements $(i = 1,...,k)$,

R_j^{*} - the amount of the *j*-th type of resource with which specific *i*-th user requirements are partially met $(i = k+1,...,l)$,

R_j^- - the missing amount of the *j*-th type of resource due to which the *i*-th user requirements are determined $(i = l+1,...,m)$ unsatisfactory.

Depending of resources availability, two basic planning categories can be applied: *resource levelling* and *resource allocation*.

The problem of levelling resources arises in the case when there is a sufficient amount of available resources of the logistic system to meet all user requirements in the observed planning period entirely. Here, it is essential to fulfill the condition of timeliness of satisfying all user requests, which is achieved by determining the order of satisfying user requests for a specific type of resource.

In this case, the needs of all users are fully met, and the solution to the problem of resource planning is unambiguous and comes down to the distribution of the size of available resources (R_j) of a series of quantities (B_{ij}), where the condition is satisfied:

$$B_j = \sum_{i=1}^{m} B_{ij} \le R_j \qquad (2)$$

The size R_j represents the available amount of resources, i.e. $R_j = R_j^{'} + r_j$, where the size $R_j^{'}$ represents the number of resources that are allocated to user requirements, while r_j represents the number of resources that remain after distribution, i.e. represents the excess resources for the observed planning period.

The problem of resource allocation occurs when resources are limited, i.e. insufficient to meet all user needs in the observed planning period, which can be mathematically represented with the following expression:

$$B_j = \sum_{i=1}^{m} B_{ij} > R_j \qquad (3)$$

In this case, there is a shortage of resources, which for the *j*-th type of resource is:

$$\Delta R_j = B_j - R_j \qquad (4)$$

The size ΔR_j should be taken away from the users in some way to cover the existing lack of required resources.

The solution to this problem comes down to allocating the available amount of the resources R_j^* to the order of new quantities b_{ij}^* to satisfy the following condition:

$$R_j^* = \sum_{i=1}^{m} b_{ij}^* \text{ , respectively } R_j^* = \sum_{i=1}^{m} B_{ij} - \Delta R_j \qquad (5)$$

This can be done by shortening the required amount of resources to each user by the number of missing resources δ_{ij}, so that ΔR_j represents the total amount of missing resources that could cover the resulting shortage or meet the condition:

$$\Delta R_j = \sum_{i=1}^{m} \delta_{ij} \qquad (6)$$

where: δ_{ij} - reduced amount of the *j*-th resource to the *i*-th user.

Research on resource allocation problems shows that ranking user requests according to the degree of importance, seeking or sharing the same resource, is an important activity when deadlines are short and resources are limited (Lehtola et al, 2004). Requirements prioritization is the setting of ranks or ratings of importance to a set of requirements based on specific criteria and according to the viewpoints of various stakeholders (Moisiadis, 2002, Ogryczak et al, 2014).

In addition, when ranking the requests, what is important is the method of determining the coefficient of the significance of the request concerning the obtained rank.

From the set conditions and specific priority requests of the user (K_{ij}) for a specific type of resource, the *coefficient of the significance of the request* of the *i*-th user for the *j*-th type of resource can be determined $(\mu_{ij} \in [0,1])$.

From the above conditions, the appropriate *relative coefficient of the significance* of satisfying the user's request for the *j*-th type of resource (β_{ij}), whose value is:

$$\beta_{ij} = \frac{B_{ij}}{\mu_{ij} \cdot \sum_{j=1}^{n} \sum_{i=1}^{m} \left(B_{ij} / \mu_{ij} \right)} \qquad (7)$$

where:

B_{ij} - the size of the required *j*-th type of resources by the *i*-th user for the observed planning period,
μ_{ij} - the coefficient of the significance of the request of the *i*-th user for the *j*-th type of resource, and
m - number of users.

In that case, the reduced amount of the *j*-th resource to the *i*-th user can be determined by the following relation:

$$\delta_{ij} = \beta_{ij} \cdot \sum_{j=1}^{n} \Delta R_j \qquad (8)$$

In this situation, the amount of the *j*-th resource allocated to the *i*-th user is:

$$b_{ij}^{*} = B_{ij} - \delta_{ij} \qquad (9)$$

The assessment of meeting the requirements of the *i*-th user with the *j*-th type of resources after reducing the planned amount is determined by the coefficient of individual service of the user:

$$\lambda_{ij} = \frac{b_{ij}^{*}}{B_{ij}} \qquad (10)$$

In this way, it is ensured that the coefficient of individual customer service λ_{ij} is equal to the coefficient of the average service $\overline{\lambda}_j$ of all p users $(0 < p \leq m)$ with the same priority of satisfying the requirements with the *j*-th type of resource.

In this case, the coefficient of average customer service with the same priority resource is:

$$\overline{\lambda}_j = \frac{\sum_{i=1}^{p} b_{ij}^{*}}{\sum_{i=1}^{p} B_{ij}} \qquad (11)$$

The procedure in this model of allocation of limited resources ensures that the Plan of allocation of limited (insufficient) resources is rational, fair, and correct for all users because all the set conditions are met.

Requirements prioritization techniques

One of the key problems of optimal allocation of limited resources is setting priorities to meet user needs. However, this problem can be overcome by using specific techniques, methods, and approaches of prioritization.

Numerous user prioritization techniques have been presented in the literature, see (Vestola, 2010; Achimugu et al, 2014; Khan et al, 2015; Qaddoura et al, 2017; Hudaib et al, 2018; Olaronke et al, 2018).

In general, request prioritization techniques can be divided in two categories. Techniques include requirement prioritization methods and requirements negotiation approaches (Olaronke et al, 2018).

Request prioritization methods are classified into methods that use a nominal scale, ordinal scale, and ratio scale, while approaches to negotiating claims focus on assigning priority to meeting requirements through consensus of stakeholders.

Nominal scale methods allow requests to be assigned to different priority groups, where all requests in one priority group are treated equally. Ordinal scale methods result in an orderly list, so it is possible to see which requirements are more important than the others, but not by how much, while relationship scale methods give a relative difference between requirements, i.e. they can quantify how much more important one request is than another. In addition to these methods, other methods are cited in the literature, such as Interval Scale, Hybridized Scale, and Machine Learning (Olaronke et al, 2018).

Each of these methods and techniques is characterized by different challenges, as none can be considered the best given the problems that accompany them, such as reliability, consistency, consensus when multiple stakeholders are involved, as well as difficulties when there is a large number of requirements, etc. In addition, some take more time but give more accurate results (Zou et al, 2019).

In practice, it becomes challenging for decision-makers to choose the correct method and technique when prioritizing requirements. In many cases, decision-makers are faced with the fact that not all requirements can be fully met due to limited resources and time. This means that it must be decided which of the requirements can be removed from the observed set of requirements and which requirements can be partially satisfied.

However, the development of models based on hybrid approaches that include a combination of different methods and techniques, as well as reaching consensus among stakeholders, can be considered as

promising models in decision-making when prioritizing customer satisfaction (Wei et al, 2021).

The Requirements triage method is a handy tool for establishing relative priorities in the assessment of resources to meet user requirements, where requests are most often classified into three groups on a nominal scale, as follows:

- High priority requirements (critical, fundamental), which must be fully met;
- Standard priority requirements (quite important), which can be partially met; and
- Low priority requirements (irrelevant, not mandatory), which do not have to be met in the observed period.

After the triage of requests, the next step is to rank those requests that can be partially met according to the degree of importance depending on their position on the ranking list.

Let $X = \{x_1, x_2, \ldots, x_n\}$ be a set of predefined options (r*equirements*), where x_i represents the *i*-th requirements $(i = 1, \ldots, n)$. Let $D = \{d_1, d_2, \ldots, d_k\}$ be a set of decision-makers, where d_k denotes the *k*-th decision-maker $(k = 1, \ldots, m)$. Each decision-maker $d_k \in D$ can express their preference information using different preference structures.

The procedure of the rank selection process is given as follows:

Step 1: Obtaining the individual preference vectors

Let $R_k = \{r_1^k, r_2^k, \ldots, r_n^k\}$ the individual ranking vector, where r_i^k represents the *i*-th rank of requirements $(i = 1, \ldots, n)$, which is given by the decision-maker d_k.

Step 2: Obtaining the collective preference vectors

After obtaining individual preference vectors by different decision-makers, for calculating the collective preference vector $R_c = \{r_1^c, r_2^c, \ldots, r_n^c\}$, where r_i represents the *i*-th rank of requirements $(i = 1, \ldots, n)$, in this paper, the heuristic algorithm of the median Kemenia is applied (Milićević & Milenkov, 2014).

Step 3: Consensus reaching process

A consensus-reaching process is a dynamic and iterative group-discussion process that helps the decision-makers to bring their opinions closer before making a decision (Pérez, 2018). This process consists of several rounds where the decision-makers discuss and change their preferences according to the suggestions given by a moderator. Usually, the moderator is a person who does not participate in the discussion, but he or she helps the decision-makers to make their preferences closer to each other. The moderator's tasks are 1) computing the consensus measures, 2) checking the level of agreement, and 3) generating some advice for those decision-makers that should change their minds.

To calculate the level of consensus, the ordinal consensus degree (OCD) measures is applied in this paper, The OCD is defined as the deviation between individual preference vectors and collective preference vectors (Dong & Zhang, 2014), as follows:

$$OCD(d_k) = \frac{1}{n^2}\sum_{i=1}^{n}\left|r_i^k - r_i^c\right| \tag{12}$$

The ordinal consensus degree among all decision-makers is given as follows:

$$OCD\{d_1, d_2, \ldots, d_m\} = \frac{1}{m}\sum_{k=1}^{m} OCD(d_k) \tag{13}$$

If the $OCD(d_1, d_2, \ldots, d_m) = 0$, then all decision-makers have complete ordinal consensus with the collective option. Otherwise, the smaller $OCD\{d_1, d_2, \ldots, d_m\}$ value indicates the higher ordinal consensus level among $\{d_1, d_2, \ldots, d_m\}$.

When the level of consensus is not met, a feedback adjustment procedure is applied to improve the level of consensus among decision-makers, which is repeated until a predetermined level of consensus is reached α (Tang et al, 2021).

Methods of converting ranks into weighting coefficients

Ranking user requirements and then converting ranks into weights has certain advantages. The main advantage of this method of determining the significance of user requests is that it is much easier to rank user requests by applying specific methods of prioritization, and then based on the obtained unified list of n prioritized (ranked) requirements, determine the weighting coefficients of the significance of

the requirements by applying specific methods for converting ranks into weight values (Tufail et al, 2019).

In the literature (Milićević & Milenkov, 2014; Alfares & Duffuaa, 2016), several methods for determining the weight values of the coefficients based on their rank are presented. The following methods were used in this paper:

1) Variable-slope linear (VSL) weights:

$$w_r = 100 - \left(3.19514 + \frac{37.75756}{n}\right) \cdot (r-1) \quad (14)$$

2) Rank-sum (RS) weights:

$$w_r = 100 \cdot (n+1-r)/n \quad (15)$$

3) Rank reciprocal (RR) weights:

$$w_r = 100/r \quad (16)$$

4) Rank order centroid (ROC) weights:

$$w_r = \frac{100 \cdot \sum_{i=r}^{n} 1/i}{\sum_{i=1}^{n} 1/i} \quad (17)$$

5) Geometric weights (GW):

$$w_r = \frac{100}{\left(\sqrt{2}\right)^{r-1}} \quad (18)$$

where:

w_r - weight value of the coefficient of significance of the request,

r - rank required, n - the total number of user requests.

The weight values of the coefficient of the significance of the requirements obtained by these methods are in the range from 0 to 100. By additive normalization, these values are reduced to the interval 0-1.

In this paper, the aggregation of the weight values of the coefficient is performed by arithmetic averaging of the obtained values using the above methods, with the following expression:

$$W_j = \frac{\sum_{i=1}^{q} w_{ij}}{q} \quad (19)$$

where:

q - the number of methods applied, and

$j = 1,2,\ldots,n$ - the user request number.

Application of the resource allocation model

For the observed planning period, the requirements of 5 users who use the same resource of the logistics system were analyzed.

The logistics support planning process was implemented through the following steps shown in Figure 2:

Step 1: Determine user requirements for a particular type of resource

After the analysis, the user requirements were grouped into ten homogeneous groups, with the total required capacity $B_j = 7000$ of resource units, as shown in Table 1.

Table 1 – Overview of the user requests for the same type of resource
Таблица 1 – Обзор запросов пользователей по одинаковому типу ресурса
Табела 1 – Преглед захтева корисника за исту врсту ресурса

	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**B10**	**Total**
K1	300	200	0	100	100	100	250	100	150	200	**1500**
K2	100	200	100	200	300	150	150	100	200	200	**1700**
K3	0	0	200	100	150	300	200	50	100	0	**1100**
K4	200	0	0	300	300	50	100	100	250	200	**1500**
K5	0	100	200	50	150	0	300	150	100	150	**1200**
Total	**600**	**500**	**500**	**750**	**1000**	**600**	**1000**	**500**	**800**	**750**	**7000**

Step 2: Determining the available capacities of the logistics system for the required type of resources

For the observed planning period, it was determined that the logistics system for the required type of resources has a capacity of $R_j = 5000$ units of measure.

Step 3: Determining the deviation of the required (required) from the available resource capacity

Given that the total required resource capacity of the user is $B_j = 7000$ units of measure and that the logistics system has the resource capacity of $R_j = 5000$ units of measure, there is a shortage of resources in the system of $\Delta R_j = B_j - R_j = 7000 - 5000 = 2000$ units of measure.

Step 4: Select a customer satisfaction policy.

The choice of customer satisfaction policy plays a key role, given the present deficit of resource capacity of the logistics system. In this regard, the "Priority of Requirements" rule has proven in practice to be a very effective policy for the allocation of limited resources.

In this paper, the technique of *request triage* was first applied, where after the analysis, it was decided which requirements will be fully satisfied, which partially, and which will not be served. After that, the technique of ranking the partially met requirements was applied to determine their degree of significance to achieve the greatest global usefulness of the system.

Step 4.1: Application of the triage requirement technique

By applying the request triage technique, the decision-makers decided that the requests of users B7, B8, and B9 were fully met, and the request of B10 was not met. It was also decided that other requirements would be partially met by all users.

Table 2 – Overview of the user requirements after the triage
Таблица 2 – Обзор запросов пользователей после сортировки
Табела 2 – Преглед захтева корисника након тријаже

	B1	**B2**	**B3**	**B4**	**B5**	**B6**	**Total**
K1	300	200	0	100	100	100	**800**
K2	100	200	100	200	300	150	**1050**
K3	0	0	200	100	150	300	**750**
K4	200	0	0	300	300	50	**850**
K5	0	100	200	50	150	0	**500**
Total	**600**	**500**	**500**	**750**	**1000**	**600**	**3950**

Following the request triage procedure, the total required resource capacity of the users is $B_j = 3950$ units of measure, and the available resource capacity of the logistics system is now $R_j = 2700$ units of measure. So, there is still a deficit of resources in the system, which now amounts to:

$$\Delta R_j = B_j - R_j = 3950 - 2700 = 1250$$

Step 4.2: Ranking the requests that are partially served

In the process of determining the degree of significance of the requests that are partially served, five decision-makers participated in ranking the requests B1, B2, B3, B4, B5, and B6.

Table 3 provides an overview of the ranked user requirements by the decision-makers.

Table 3 – Overview of the ranked user requests by the decision makers
Таблица 3 – Проверка ранжированных запросов пользователей ответственным лицом, принимающим решения
Табела 3 – Преглед рангираних захтева корисника од стране доносиоца одлуке

Decision-makers	B1	B2	B3	B4	B5	B6
DM1	1	2	4	3	6	5
DM2	1	2	3	4	6	5
DM3	3	1	2	5	4	6
DM4	1	2	3	4	5	6
DM5	2	1	3	5	4	6

Step 4.3: Consolidate individually ranked requests into a group rank

Consolidation of individually ranked requests by a group of decision-makers into the final group order was done by applying *the heuristic algorithm to determine the Kemeny median.*

After performing the procedure of binary relations between ranking pairs, the obtained elements of the loss matrix are shown in Table 4.

Table 4 – Loss matrix element values
Таблица 4 – Значения элементов матрицы потерь
Табела 4 – Вредности елемената матрице губитака

	B1	B2	B3	B4	B5	B6
B1	0	6	2	0	0	0
B2	4	0	0	0	0	0
B3	8	10	0	2	0	0
B4	10	10	8	0	4	0
B5	10	10	10	6	0	4
B6	10	10	10	10	6	0

Table 5 shows the procedure for applying the Kemeny median algorithm to obtain the final group order of user requests in accordance with the degree of significance.

Table 5 – Application of the heuristic algorithm of the Kemeny median to obtain a group order
Таблица 5 – Применение эвристического алгоритма медианы Кемени для получения группового порядка
Табела 5 – Примена хеуристичког алгоритма медијане Кеменија за добијање групног поретка

	$s_i^{(1)}$	$s_i^{(2)}$	$s_i^{(3)}$	$s_i^{(4)}$	$s_i^{(5)}$	$s_i^{(6)}$
B1	8	**2**				
B2	**4**					
B3	30	10	**2**			
B4	34	22	12	**4**		
B5	42	30	20	10	**4**	
B6	26	36	26	16	6	**0**

The final group rank of the requests is B2, B1, B3, B4, B5, and B6.

Step 4.4: To calculate consensus levels

By applying Eqs. (12) and Eqs. (13), the level of consensus is calculated, which is $OCD = 0.08889$. The obtained level of consensus is satisfactory, which means that the decision-makers do not need to adjust their preferences.

Step 4.5: Determining the weight values of the coefficient of the significance of the requirements

Table 6 shows the weight values of the coefficients of the significance of the requirements based on their rank, obtained by applying the method of converting the ranks into weight values.

Table 6 – Weight values of the coefficient of significance of the request
Таблица 6 – Весовые значения коэффициента значимости запроса
Табела 6 – Тежинске вредности коефицијената значајности захтева

	B2	B1	B3	B4	B5	B6
VLS	0.2185	0.1978	0.1770	0.1563	0.1356	0.1148
RS	0.2857	0.2381	0.1905	0.1429	0.0952	0.0476
RR	0.4082	0.2041	0.1361	0.1020	0.0816	0.0680
ROC	0.4083	0.2417	0.1583	0.1028	0.0611	0.0278
GW	0.3347	0.2367	0.1674	0.1183	0.0837	0.0592
Wj	**0.2763**	**0.2181**	**0.1714**	**0.1375**	**0.1101**	**0.0866**

Step 5: Development of alternative planning solutions

By applying the model, alternative solutions for selecting the optimal Logistic Support Plan have been developed, depending on the weight values of the coefficients of the significance of the requirements μ_j, which are shown in Table 7.

From Table 7, it can be seen that the difference between the maximum and minimum values of the percentage of customer service in the VLS method is 18.80, in the RS method 55.08, In the RR method 41.26, in the ROC method 69.33, while in the GW method it is 46.26.

The difference between the maximum and minimum values of the percentage of customer service in the arithmetically combined group value of weight coefficients W_j is 33.08.

Step 6: Selection of the planning solution

After analysing acceptable planning solutions for developing the optimal Logistic Support Plan, the resource allocation was selected based on the values of weighting coefficients W_j.

Step 7: Detailed elaboration of the selected planning solution

In this step, a customer service order with the allocated amount of resources in the observed planning period is elaborated.

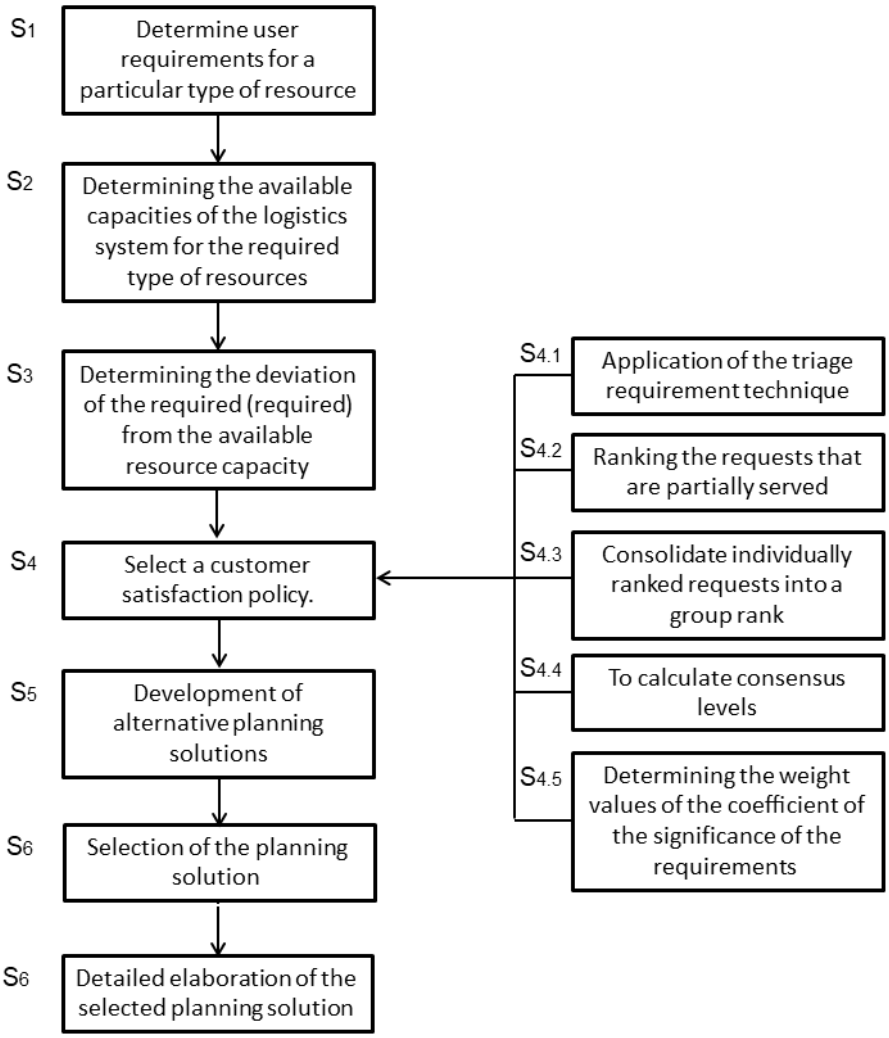


Figure 2 – Flowchart of the proposed methodology
Рис. 2 – Блок-схема предлагаемой методологии
Слика 2 – Дијаграм тока предложене методологије

Table 7 – Display of the amount of allocated resources depending on the weight values of the coefficients of significance of the request

Таблица 7 – Отображение количества выделенных ресурсов в зависимости от весовых значений коэффициентов значимости запроса

Табела 7 – Приказ количине алоцираних ресурса у зависности од тежинских вредности коефицијената значајности захтева

Zahtev	Rang	Korisnik	μj						Bij	VLS			RS			RR			ROC			GW			Wj		
			VLS	RS	RR	ROC	GW	Wj		δij	bij*	(%)	δij	bij*	(%)	δij	bij*	(%)	δij	bij*	(%)	δij	bij*	(%)	δij	bij*	(%)
B2	1	K1	0.2185	0.2857	0.4082	0.4083	0.3347	0.2763	300	66	234	78.08	33	267	88.99	25	275	91.75	15	285	94.93	30	270	90.06	45	255	84.90
		K2							100	22	78		11	89		8	92		5	95		10	90		15	85	
		K4							200	44	156		22	178		16	184		10	190		20	180		30	170	
B1	2	K1	0.1978	0.2381	0.2041	0.2417	0.2367	0.2181	200	48	152	75.79	26	174	86.79	33	167	83.50	17	183	91.44	28	172	85.94	38	162	80.87
		K2							200	48	152		26	174		33	167		17	183		28	172		38	162	
		K5							100	24	76		13	87		16	84		9	91		14	86		19	81	
B3	3	K1	0.1770	0.1905	0.1361	0.1583	0.1674	0.1714	100	27	73	72.95	17	83	83.49	25	75	75.26	13	87	86.93	20	80	80.12	24	76	75.66
		K2							150	41	109		25	125		37	113		20	130		30	120		37	113	
		K3							300	81	219		50	250		74	226		39	261		60	240		73	227	
		K4							50	14	36		8	42		12	38		7	43		10	40		12	38	
B4	4	K2	0.1563	0.1429	0.1020	0.1028	0.1183	0.1375	100	31	69	69.36	22	78	77.99	33	67	66.99	20	80	79.88	28	72	71.87	30	70	69.66
		K3							200	61	139		44	156		66	134		40	160		56	144		61	139	
		K5							200	61	139		44	156		66	134		40	160		56	144		61	139	
B6	5	K1	0.1356	0.0952	0.0816	0.0611	0.0837	0.1101	100	35	65	64.69	33	67	66.96	41	59	58.74	34	66	66.15	40	60	60.25	38	62	62.11
		K2							200	71	129		66	134		83	117		68	132		80	120		76	124	
		K3							100	35	65		33	67		41	59		34	66		40	60		38	62	
		K4							300	106	194		99	201		124	176		102	198		119	181		114	186	
		K5							50	18	32		17	33		21	29		17	33		20	30		19	31	
B5	6	K1	0.1148	0.0476	0.0680	0.0278	0.0592	0.0866	100	42	58	58.29	66	34	33.91	50	50	50.49	74	26	25.60	56	44	43.80	48	52	51.82
		K2							300	125	175		198	102		149	151		223	77		169	131		145	155	
		K3							150	63	87		99	51		74	76		112	38		84	66		72	78	
		K4							300	125	175		198	102		149	151		223	77		169	131		145	155	
		K5							150	63	87		99	51		74	76		112	38		84	66		72	78	

Conclusion

In logistics systems, there is often a need to make decisions regarding the allocation of limited resources. Resource allocation efficiency is measured by optimizing appropriate parameters such as demand size, resource capacity, task execution time, system latency, and cost, which are key elements in planning the logistics support of military operations.

The considerable uncertainty and dynamics of the requirements generated by military units (users of logistic products and services), and, on the other hand, numerous limitations present in logistics indicate that logistics support planning is a crucial and challenging area of logistics.

Optimal planning reduces or eliminates the uncertainty of future activities and maintains the system within the permissible (tolerant) framework of functionality in the observed future period.

To plan logistics support well, it is necessary to have reliable data on customer requirements, as well as data on the availability of limited resources of the logistics system. In addition, quality planning implies applying modern methods, techniques, and software tools, which will provide greater rationality and objectivity in determining the variants of planning solutions.

This paper has shown that techniques for prioritizing customer requirements and resource allocation provide a possibility of agile planning of logistics support and ensure optimal allocation of limited resource capacities of the logistic system. The goal in future research is to consider the possibility of applying the allocation of multiple resources, in multiperiod, according to priorities, and by substitution of resources to finally obtain, as much as it is possible, an automated logistics support plan ready to respond to all possible scenarios.

Due to the extraordinary dynamism and heterogeneity of phenomena in logistics activities, logistics support planning cannot be fully and easily formalized and automated. In that sense, the efficiency of logistics support planning depends on creativity, organizational skills, and innovation in the work of logistics staff.

References

Achimugu, P., Selamat, A., Ibrahim, R. & Mahrin, M.N. 2014. A systematic literature review of software requirements prioritization research. *Information and Software Technology*, 56(6), pp.568-585. Available at: https://doi.org/10.1016/j.infsof.2014.02.001.

Alfares, H.K. & Duffuaa, S.O. 2016. Simulation-based evaluation of criteria rank-weighting methods in multi-criteria decision-making. *International Journal of Information Technology & Decision Making*, 15(01), pp.43-61. Available at: https://doi.org/10.1142/S0219622015500315.

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., Nikolić, N. & Stojković, D. 2004. Logistička podrška logističkim operacijama. *Vojnotehnički glasnik /Military Technical Courier,* 52(3-4), pp.275-285 (in Serbian). Available at: https://doi.org/10.5937/vojtehg0404275A.

Chevaleyre, Y., Dunne, P., Endriss, U., Lang, J., Lemaıtre, M., Maudet, N., Padget, J., Phelps, S., Rodrıguez-Aguilar, J. & Sousa, P. 2006. Issues in multiagent resource allocation*. Informatica,* 30(1), pp.3-31 [online]. Available at: https://www.informatica.si/index.php/informatica/article/view/70 [Accessed: 5 July 2021].

Daoud, A., Balbo, F., Gianessi, P. & Picard, G. 2021. A Generic Multi-Agent Model for Resource Allocation Strategies in Online On-Demand Transport with Autonomous Vehicles. In: *Proceedings of the 20th International Conference AAMAS 2021,* London, UK, p.3, May, hal-03093017 [online]. Available at: https://tel.archives-ouvertes.fr/DEMO-ENSMSE/hal-03093017v1 [Accessed: 5 July 2021].

Dong, Y. & Zhang, H. 2014. Multiperson decision making with different preference representation structures: A direct consensus framework and its properties. *Knowledge-Based Systems*, 58, pp.45-57. Available at: https://doi.org/10.1016/j.knosys.2013.09.021.

Hameed, A., Khoshkbarforoushha, A., Ranjan, R., Jayaraman, P.P., Kolodziej, J., Balaji, P., Zeadally, S, Malluhi, Q.M., Tziritas, N., Vishnu, A., Khan, S.U. & Zomaya, A. 2016. A survey and taxonomy on energy-efficient resource allocation techniques for cloud computing systems. *Computing*, 98(7), pp.751-774. Available at: https://doi.org/10.1007/s00607-014-0407-8.

Hudaib, A., Masadeh, R., Qasem, M. & Alzaqebah, A. 2018. Requirements prioritization techniques comparison. *Modern Applied Science*, 12(2), pp.62-80. Available at: https://doi.org/10.5539/mas.v12n2p62.

Hurley, P.C.Jr & Coleman, H.H. 2018. What FM 3-0 means for expeditionary battlefield sustainment. *Army Sustainment,* May-June [online]. Available at: https://www.army.mil/article/203894 [Accessed: 5 July 2021].

Jia, Q., Wang, T-n & Zhang, Y-c. 2020. A New Mode of Army Equipment Support. *Journal of Physics: Conference Series,* 1649, pp.1-8. Available at: https://doi.org/10.1088/1742-6596/1649/1/012042.

Khan, J.A., Rehman, I.U., Khan, Y.H., Khan, I.J. & Rashid, S. 2015. Comparison of Requirement Prioritization Techniques to Find Best Prioritization Technique. *International Journal of Modern Education & Computer Science*, 7(11), pp.53-59. Available at: https://doi.org/10.5815/ijmecs.2015.11.06.

Kostiuchenko, L. & Solomon, D. 2020. The basic terminology of the modern military logistics. *Intellectualization of logistics and supply chain management,* 1(1), pp.91-98. Available at: https://doi.org/10.46783/smart-scm/2020-1-8.

Lehtola, L., Kauppinen, M. & Kujala, S. 2004. Requirements Prioritization Challenges in Practice. In: *Bomarius, F. & Iida, H. (Eds.) Product Focused Software Process Improvement. PROFES 2004. Lecture Notes in Computer Science,* 3009, pp.497-508*.* Springer, Berlin, Heidelberg. Available at: https://doi.org/10.1007/978-3-540-24659-6_36. ISBN: 978-3-540-24659-6.

Li, X., Li, A. & Guo, X. 2020. The sustainable development-oriented development and utilization of renewable energy industry – A comprehensive analysis of MCDM methods. *Energy*, 212(art.number:118694). Available at: https://doi.org/10.1016/j.energy.2020.118694.

Luss, H. 1999. On Equitable Resource Allocation Problems: A Lexicographic Minimax Approach. *Operations Research* 47(3), pp.361-378, Available at: https://doi.org/10.1287/opre.47.3.361.

Luss, H. 2012. *Equitable resource allocation: Models, Algorithms, and Applications.* Hoboken, NJ: John Wiley & Sons. ISBN: 978-1-118-05468-0.

McConnell, B.M., Hodgson, T.J., Kay, M.G., King, R.E., Liu, Y., Parlier, G.H., Thoney-Barletta, K. & Wilson, J.R. 2021. Assessing uncertainty and risk in an expeditionary military logistics network*. Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, 18(2), pp.135-156. Available at: https://doi.org/10.1177/1548512919860595.

McConnell, B.M. & King, R. 2019. *Expeditionary Logistics Analysis for Decision Support*. *Technical Report.* North Carolina State University Raleigh United States [online]. Available at: https://apps.dtic.mil/sti/citations/AD1092064 [Accessed: 5 July 2021].

Meran, G., Siehlow, M. & von Hirschhausen, C. 2021. *Integrated Water Resource Management: Principles and Applications*. In: *The Economics of Water*, pp.23-121. Springer, Cham. Available at: https://doi.org/10.1007/978-3-030-48485-9_3. ISBN: 978-3-030-48485-9.

Milenkov, M.A., Sokolović, V.S., Milovanović, V.R. & Milić, M.D. 2020. Logistics: Its role, significance and approaches. *Vojnotehnički glasnik/Military Technical Courier*, 68(1), pp.79-106. Available at: https://doi.org/10.5937/vojtehg68-24805.

Milićević, M.R., & Milenkov, M.A. 2014. Determination of criteria weights using ranking. *Vojnotehnički glasnik/Military Technical Courier*, 62(1), pp.141-166 (in Serbian). Available at: https://doi.org/10.5937/vojtehg62-3878.

Moisiadis, F. 2002. The fundamentals of prioritizing requirements. In: *Proceedings of the systems engineering, test and evaluation conference* (SETE'2002), Sydney, Australia, October [online]. Available at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.92.4036&rep=rep1&type=pdf [Accessed: 6 July 2021].

Ogryczak, W., Luss, H., Pióro, M., Nace, D. & Tomaszewski, A. 2014. Fair optimization and networks: A survey. *Journal of Applied Mathematics*, art.ID:612018. Available at: https://doi.org/10.1155/2014/612018.

Olaronke, I., Rhoda, I. & Ishaya, G. 2018. An appraisal of software requirement prioritization techniques. *Asian Journal of Research in Computer Science*, 1(1), pp.1-16. Available at: https://doi.org/10.9734/ajrcos/2018/v1i124717.

Pamučar, D.S. & Savin, L.M. 2020. Multiple-criteria model for optimal off-road vehicle selection for passenger transportation: BWM-COPRAS model. *Vojnotehnički glasnik/Military Technical Courier*, 68(1), pp.28-64. Available at: https://doi.org/10.5937/vojtehg68-22916.

Pérez, I.J., Cabrerizo, F.J., Alonso, S., Dong, Y.C., Chiclana, F. & Herrera-Viedma, E. 2018. On dynamic consensus processes in group decision making problems. *Information Sciences*, 459, pp.20-35. Available at: https://doi.org/10.1016/j.ins.2018.05.017.

Qaddoura, R., Abu-Srhan, A., Qasem, M.H. & Hudaib, A. 2017. Requirements prioritization techniques review and analysis. In: *2017 International Conference on New Trends in Computing Sciences (ICTCS)*, Amman, Jordan, pp.258-263, October 11-13. Available at: https://doi.org/10.1109/ICTCS.2017.55.

Rogers, M.B., McConnell, B.M., Hodgson, T.J., Kay, M.G., King, R.E., Parlier, G. & Thoney-Barletta, K. 2018. A Military Logistics Network Planning System. *Military Operations Research*, 23(4), pp.5-24 [online]. Available at: https://www.jstor.org/stable/26553094 [Accessed: 5 July 2021].

Sarma, D., Das, A., Dutta, P. & Bera, U.K. 2020. A Cost Minimization Resource Allocation Model for Disaster Relief Operations With an Information Crowdsourcing-Based MCDM Approach. *IEEE Transactions on Engineering Management,* pp.1-21., Available at: https://doi.org/10.1109/TEM.2020.3015775.

Schwartz, B., McConnell, B.M. & Parlier, G.H. 2019. How Data Analytics Will Improve Logistics Planning. *Army Sustainment,* 51(3), pp.54-57 [online]. Available at: https://alu.army.mil/alog/ARCHIVE/PB700201903FULL.pdf [Accessed: 5 July 2021].

Skobelev, P. 2011. Multi-agent systems for real-time resource allocation, scheduling, optimization and controlling: industrial applications. In: *Mařík, V., Vrba, P., Leitão, P. (Eds.) Holonic and Multi-Agent Systems for Manufacturing. HoloMAS 2011. Lecture Notes in Computer Science,* 6867, pp.1-14. Berlin, Heidelberg: Springer. Available at: https://doi.org/10.1007/978-3-642-23181-0_1. ISBN: 978-3-642-23181-0.

Tang, H., Wan, S., Li, C-C., Liang, H. & Dong, Y. 2021. Consensus Reaching Process in the Two-Rank Group Decision-Making with Heterogeneous Preference Information. *International Journal of Computational Intelligence Systems*, 14(1), pp.758-768. Available at: https://doi.org/10.2991/ijcis.d.210201.001.

Tufail, H., Qasim, I., Masood, M.F., Tanvir, S. & Butt, W.H. 2019. Towards the selection of Optimum Requirements Prioritization Technique: A Comparative Analysis. In: *The 5th International Conference on Information Management,* Cambridge, UK, pp.227-231, March 24-27. Available at: https://doi.org/10.1109/INFOMAN.2019.8714709.

Vestola, M. 2010. *A comparison of nine basic techniques for requirements prioritization,* pp.1-8. Helsinki University of Technology [online]. Available at: http://www.mvnet.fi/publications/software_development_seminar.pdf [Accessed: 5 July 2021].

Wei, X., Quan, S., , Shi zhuang, Y, Yan song, A. & Gang, Q. 2021. Research on Dynamic Resource Allocation and Decision-making Model of Equipment Independent Maintenance. *Journal of Physics: Conference Series,* 1939, pp.1-9. Available at: https://doi.org/10.1088/1742-6596/1939/1/012014.

Zeimpekis, V., Kaimakamis, G. & Daras, N.J. 2015. *Military logistics: research advances and future trends.* Springer. Available at: https://doi.org/10.1007/978-3-319-12075-1. ISBN: 978-3-319-12075-1.

Zlatnik, D. & Mares, J. 2020. Ammunition supplies, new proposal of ammunition sufficiency. *Vojnotehnički glasnik/Military Technical Courier,* 68(2), pp.250-267. Available at: https://doi.org/10.5937/vojtehg68-25193.

Zou, H., Liu, D., Guo, S., Xiong, L., Liu, P., Yin, J., Zeng, Y., Zhang, J. & Shen, Y. 2019. Quantitative assessment of adaptive measures on optimal water resources allocation by using reliability, resilience, vulnerability indicators. *Stochastic Environmental Research and Risk Assessment,* 34, pp.103-199. Available at: https://doi.org/10.1007/s00477-019-01753-4.

МОДЕЛЬ ПЛАНИРОВАНИЯ ЛОГИСТИЧЕСКОЙ ПОДДЕРЖКИ В УСЛОВИЯХ ОГРАНИЧЕННЫХ РЕСУРСОВ

Никола Б. Симич[а], *Марьян* А. Миленков[а],
Владимир Р. Милованович[а], *Влада* С. Соколович[а], **корреспондент,**
Павел Й. Фольтин[б], *Балаж* Й. Такшас[в]

[а] Университет обороны в г. Белград, Военная академия, Департамент логистики, г. Белград, Республика Сербия

[б] Университет обороны в Брно, факультет военного руководства, Департамент материально-технического обеспечения, г. Брно, Чешская Республика

[в] Университет государственной службы, факультет военных наук и подготовки офицеров, факультет снабжения, финансов и военного транспорта, г. Будапешт, Венгрия

РУБРИКА ГРНТИ: 81.00.00 ОБЩИЕ И КОМПЛЕКСНЫЕ ПРОБЛЕМЫ ТЕХНИЧЕСКИХ И ПРИКЛАДНЫХ НАУК И ОТРАСЛЕЙ НАРОДНОГО ХОЗЯЙСТВА:
81.88.00 Материально-техническое снабжение. Логистика;
81.88.75 Экономика, организация, управление, планирование и прогнозирование в материальнотехническом снабжении

ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение: В статье представлена модель планирования логистической поддержки в условиях ограниченных логистических ресурсов, основанная на приоритезации запросов клиентов и распределении ресурсов. Лица, принимающие решения, играют ключевую роль в эффективном и справедливом распределении ресурсов, поскольку они определяют приоритеты среди различных запросов пользователей.

Методы. Для определения степени важности требований пользователя были применены методы приоритизации запросов с использованием номинальной шкалы, порядковой шкалы и шкалы отношений, а также пять методов преобразования ранга в весовые коэффициенты. Метод сортировки запросов использовался для определения относительных приоритетов, в то время как эвристический алгоритм определения медианы Кемени использовался для объединения индивидуально ранжированных запросов в групповой ранг. Чтобы уравновесить противоположные требования пользователей, использовались консенсусные меры группового принятия решений. Для получения оптимального планировочного решения логистической поддержки применены методы и приемы распределения ресурсов.

Результаты: Разработана модель адаптивного планирования логистической поддержки в условиях ограниченных ресурсных возможностей логистической системы.

Вывод: Предложенная модель может быть эффективно применена и в других сферах распределения ресурсов.

Ключевые слова: планирование логистики, приоритезация запросов, сортировка, преобразование рангов веса, распределение ресурсов.

МОДЕЛ ПЛАНИРАЊА ЛОГИСТИЧКЕ ПОДРШКЕ У УСЛОВИМА ОГРАНИЧЕНИХ РЕСУРСА

Никола Б. Симић[а], *Марјан* А. Миленков[а],
Владимир Р. Миловановић[а], *Влада* С. Соколовић[а], **аутор за преписку,**
Павел Ј. Фолтин[б], *Балаж* Ј. Такшас[в]

[а] Универзитет одбране у Београду, Војна академија, Катедра логистике, Београд, Република Србија

[б] Универзитет одбране у Брну, Факултет за војно руководство, Одсек за логистику, Брно, Чешка Република

[в] Универзитет за јавне службе, Факултет војних наука и обуку официра, Одсек за снабдевање, финансије и војни саобраћај, Будимпешта, Мађарска

ОБЛАСТ: логистика, инжињерски менаџмент, информационе технологије
ВРСТА ЧЛАНКА: оригинални научни рад

Сажетак:

Увод: У раду је представљен модел планирања логистичке подршке у условима ограничених логистичких ресурса на основу приоритизације захтева купаца и алокације ресурса. Доносиоци одлука имају кључну улогу у ефикасној и правичној алокацији ресурса јер дају приоритет различитим захтевима корисника.

Методе: Технике приоритизације захтева које користе номиналну скалу, ординалну скалу и скалу односа, као и пет метода за претварање ранга у тежинске коефицијенте, примењене су како би се одредио степен значаја захтева корисника. За утврђивање релативних приоритета коришћен је метод тријаже захтева, док је хеуристички алгоритам за одређивање медијане Кеменија коришћен за консолидацију индивидуално рангираних захтева у групни ранг. Ради балансирања супротстављених захтева корисника, коришћене су мере консензуса групног одлучивања. За добијање оптималног планског решења логистичке подршке примењене су методе и технике расподеле ресурса.

Резултати: Развијен је модел за адаптивно планирање логистичке подршке у условима ограничених ресурсних капацитета логистичког система.

Закључак: Предложени модел може се ефикасно применити и у другим областима алокације ресурса.

Кључне речи: планирање логистике, приоритизација захтева, тријажа, претварање ранга у пондере, алокација ресурса.

Paper received on / Дата получения работы / Датум пријема чланка: 10.07.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 03.01.2022.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 04.01.2022.

ПРЕЛИМИНАРНА САОПШТЕЊА
ПРЕДВАРИТЕЛЬНЫЕ СООБЩЕНИЯ
PRELIMINARY COMMUNICATIONS

STATIC ABSORBER MODELLING

Milica D. Đekić
Independent researcher, Subotica, Republic of Serbia,
e-mail: milicadjekic82@gmail.com,
ORCID iD: https://orcid.org/0000-0002-3962-5951

DOI: 10.5937/vojtehg70-34776; https://doi.org/10.5937/vojtehg70-34776

ARTICLE FIELD: Binary Logics, Applied Mathematics, Informatics, Defense Industry, Computer Science, Electronics
ARTICLE TYPE: Preliminary communication

Abstract:

Introduction/purpose: A static absorber is capable of neutralizing any signal either in the physical or virtual domain and its analysis will be presented in this paper.

Methods: The approach used here includes purely scientific thoughts as well as a model with its explanations evaluated step by step applying highly sophisticated computer tools for design and simulation. No empirical results will be attached, only claims with their evidence.

Results: The crucial outcome of this research is a completely new approach to binary systems that are now observed as a set of real numbers.

Conclusion: The purpose of this research is to introduce something brand-new that can be used in cyber industry while a dynamic variation of the absorber is still under development.

Key words: cyber defense, intelligence, static absorber, signal ban, hacking, singularity, mathematical modelling.

Introduction

The first applications of binary algebra started several decades ago. The entire mathematical concept is based on the set theory which deals with two basic elements: 0 and 1. Engineers of the 20th century discovered semiconductor technology that represents 0 and 1 as the definite voltage values: 0 V and 5 V. In such a way, that paradigm has gotten its physical sense as in digital electronics where it deals with real electricity fields. The idea of the given mathematical model is quite simple and it relies on the fundamental and proven theorems of binary

logics. This paper demonstrates a complete set of mathematical models, digital circuits, and truth tables as well as proofs that serve to illustrate a digital logic scheme being capable of neutralizing any signal or a set of signals coming to its input. In other words, whatever is given at the input will be made into 0 at its output. This is feasible as any signal being ANDed with its inverted variation is equal to 0. Apparently, such a model can be assumed as a singularity in the voltage field and some testing graphs in such a context will be described. Also, this paper will introduce a completely new approach to binary algebra offering a chance to analyze such an energy area in a set of real numbers. In the essence, this modelling can serve in software and hardware production as there have been a lot of benefits from a static absorber that can be applied in cyber industry. Indeed, there have been a lot of pluses and minuses of such a solution and this article will address how to use its advantages and, consequently, avoid some drawbacks. (Djekic, 2020b), (Djekic, 2021e), (Djekic, 2021d)

In general, technology has always been a responsibility of the one who applies it and for such a reason it is important to appeal to everyone being in possession of something powerful to deal with it with selflessness, not selfishness.

It has been quite easy to pass by things without noticing anything. Once mankind has had an eye for details, it will progress much faster than ever. The nature is full of wonders that wait for humans to pay attention to them. Apparently, that is how the biggest discoveries in science were made. Next, there has been a question how well the current natural phenomena were explained and understood. For instance, it is well known that an original signal with its inversion at the input of the AND logic gate always gives 0 at the output. Boolean algebra can mathematically prove such a theorem and, indeed, digital electronics can provide these circuits to work accurately. Indeed, it has been necessary to sort things out intelligently in order to get their maximum performance. In other words, it is like testing the mathematical and logical IQ by attempting to fit the right shape object into the right opening. Another good question about such a theory could be: Where will all that energy go if anything at the input gives nothing at the output? It seems something has been very strange with such a circuit as it behaves like a singular point pulling everything inside. On the other hand, if that logic configuration were to behave like a sink, it would need better mathematical modelling to be better tackled. Also, there has been a strong need for computer simulations as well as experimental examinations in order to gain a deep insight into all scientific secrets.

Humankind may not be at that degree of technological development at present, but the ongoing tendency suggests that the modern world could be on a good track to make a better use of current endeavors.

Next, there has been a sense of wonder how such a fundamental Boolean rule could serve in cyber security. The majority of the present IT security solutions are based on binary algebra. On the other hand, the marketplace is literally overwhelmed with highly expensive, but not that effective analytical tools. In other words, cyber defense analysts sitting in their security operating centers (SOCs) can recognize if anyone has been trying to make a breach and maintain connection with some network's device, but in order to protect their asset from such an attack they need to terminate that signal manually. It is an appealing message, is it not? In the 21st century, something is still needed to be done with hands. How inconvenient?! Apparently, if it is feasible to recognize web's anomalies, it should be possible to terminate them automatically letting only trusted devices exchange the information with a well-protected grid. Indeed, there has been something which could absorb any signal and if there were an opportunity to pass only untrusted connections through that absorber, all unwanted behaviors would be banned in a sub-second period of time. No more breaches, right? At this stage, it is about how to prevent or probably reduce such a concern; however, if the right things are put into right places, the best possible performances are expected. (Djekic, 2017), (Đekić, 2021)

In a similar way, hackers can get a brilliant idea creating a malware that can neutralize the internet connectivity and put into quarantine any infected object. In total, everything is still an idea which can become a reality in the coming time.

The purpose of this idea is to improve the effectiveness of the incident response turning active defense into the passive one or, in other words - converting monitoring and incident responses into extremely intelligent prevention. There has been a need to develop a computer code very smartly so that it could differentiate trusted from untrusted behaviors on the web. (Djekic, 2021a), (Djekic, 2021b), (Djekic, 2021c)

Maybe it is not that much about artificial intelligence as it has been about allowing the communication through a well-developed algorithm that can make a decision, not think for real. Also, there is a need for anti-breach software, where the attacker leaves an IP address, but cannot establish communication with a targeted device for being rejected any time an attempt occurs. In other words, it is a sort of communication filtering and quite good protection due to which cyber warfare could be history if appropriately applied. The entire concept can be imagined as

the informatics body armor of cyber warriors that cannot be wounded or killed on their positions once they apply such a shield. The model is called static since it uses only logic gates without returning branches that could consist of some memory elements.

Mathematical models using binary algebra

The set theory is a well-developed and researched area of mathematics which has many applications in everyday life. On the other hand, there is binary algebra that deals with only two unique elements, 0 and 1. Such a field of science has found many usages in electronics, especially digital, as the entire modern computer science applies the results of these explorations. In this research, it has been investigated how it is possible to do modelling of logic circuits without any dynamics applied to them in order to analyze and simulate their behavior excluding real experimental conditions and laboratory testing. Also, no coding has been done in this research as it presents an idea how to develop a code so far as mathematical modelling can contribute in making both hardware and software.

A basic static absorber can be obtained if original and inverted signals are settled at the input of the AND logic gate. The mathematical description is given in equation (1) as follows:

$$B = A \cdot \overline{A} \tag{1}$$

where:

A - is an input to the AND logic gate which is in affirmation;
$\overline{A}$ - is an input to the AND logic gate which is in negation; and
B - is an output of the AND logic gate with two inputs so far.

In other words, any combination at the input will give 0 at the output causing the signal to just disappear. This is given in equation (2) as follows:

$$A \cdot \overline{A} = 0 \tag{2}$$

where:

A - is an input to the AND logic gate which is in affirmation and
$\overline{A}$ - is an input to the AND logic gate which is in negation.

This can be examined in the truth table that is given in Table 1 as follows:

Table 1 – Truth table of the initial static absorber
Таблица 1 – Таблица истинности исходного статического абсорбера
Табела 1 – Истинитосна табела иницијалног статичког апсорбера

A	B
0	0
1	0

Next, an illustration of the basic static absorber digital circuit will be provided. The illustration is made in Logic Circuit Designer software that can offer quite a reliable simulation option. Figure 1 is given as follows.

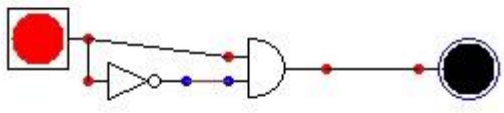


Figure 1 – Basic static absorber circuit
Рис. 1 – Базовая схема статического абсорбера
Слика 1 – Основно коло статичког апсорбера

The illustration represents the AND logic gate with 2 inputs which are, in this case, the original signal and its inverted version. If equations (1) and (2) are taken into consideration with their truth table (given in Table 1), it is quite obvious that the results of the simulation will be identical to the given mathematical description. In this case, such a model has gotten its proof and it is highly recommended that software developers make an attempt to create a program that can work as given through this modelling. Also, it is obvious that any entry at the input of this circuit will absorb the signal and give 0 as its output. Further, it will be explained why such a sort of mathematical models could be considered as a singularity as it literally neutralizes any electricity coming in. In other words, it can be discussed that everything given in equations (1) and (2) as well as in their truth table and logic diagram will be like a sink to

anything at the input. The recommendation is to go deeper into the analysis of electronic circuits in order to completely understand such semiconductor technology as well as the behavior of the applied electronic elements. Digital electronics is a field with so many areas to investigate and at this stage there has been insufficient awareness about the opportunity that such a branch of science and technology can offer so far.

This paper will demonstrate how a slightly complicated model of the static absorber can be developed. In such a case, through simple mathematics and proof using truth tables and logic simulations, it will be shown how this model can find its applications in practice. From this standpoint, it is possible to begin with a mathematical model that relies on Boolean algebra and combines the AND, OR and NOT logic functions. The description of the model is given in equation (3) as follows:

$$C = \left(A \cdot \overline{A}\right) + \left(B \cdot \overline{B}\right) \tag{3}$$

where:

A - is an input to the AND logic gate which is in affirmation;
$\overline{A}$ - is an input to the AND logic gate which is in negation;
B - is an input to the AND logic gate which is in affirmation;
$\overline{B}$ - is an input to the AND logic gate which is in negation; and
C - is an output of the OR logic gate that always gives nothing for a result as its inputs are always 0.

As given in equations (1) and (2), something AND its inversion are always equal to nothing; so, if everything is submitted into equation (3), it will be continued with equation (4) as follows:

$$C = 0 + 0 = 0 \tag{4}$$

where:

C - is an output of the OR logic gate that always gives nothing for a result as its inputs are always 0.

In practice, the OR logic gate gives nothing only if all its inputs do not have a signal as their incoming value. Such modelling can serve in

designing much complicated logic circuitries. Apparently, the real clues to this modelling can be obtained via equation (3) the truth table of which is given in Table 2 as follows:

Table 2 – Truth table of the complex static neutralizer
Таблица 2 – Таблица истинности комплексного статического нейтрализатора
Табела 2 – Истинитосна тебела комплексног статичког неутрализатора

A	B	C
0	0	0
0	1	0
1	0	0
1	1	0

The truth table given above is the evidence of the well-developed mathematical model whose logic circuit is given in Figure 2 as follows:

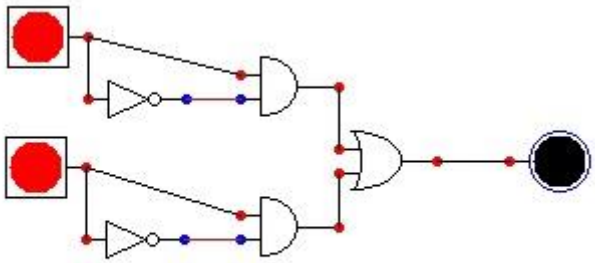


Figure 2 – Logic diagram of a complicated static absorber
Рис. 2 – Логическая схема сложного статического абсорбера
Слика 2 – Логички дијаграм компликованог статичког апсорбера

The static absorber is possible to be designed applying so simple and fundamental logic functions available in both hardware and software formats. The further research will try to handle a set of real numbers in order to examine all possibilities of an energetic field as well as some characteristics of semiconductor technology typical to silicon-based solutions. It will also introduce a kind of mathematical transformations from a set of binary numbers into a set of real numbers trying to invoke the entire new area of mathematics that could find its applications in future scientific research and explorations. In other words, it will be necessary to thoroughly understand the physical characteristics of digital

technology since it can cope, as far as it is known at this stage, with the singular points in some scalar or vector fields, suggesting maybe that future investigations will need a better understanding of the field theory. At this stage, it is feasible to offer some ideas and indeed, the entire investigation can be so time-consuming and can need a great deal of effort from the scientific community worldwide.

Examining functions in a set of real numbers

Boolean algebra is a part of the set theory that consists of two basic elements: $\{0,1\}$. It seems the binary numbers deal with duality since they can be described as a series of 0s and 1s. Quantum mechanics suggests that the entire nature deals with duality and oscillates between two basic states, matter and energy. At this stage, it is quite hasty to make any sort of correlations as there is a need for more profound research in both theoretical and empirical manner. The purpose of this effort is to bring forward some brand-new ideas and try to find a link between something already known. In this paper, it is discussed how to design a static absorber which, from the perspective of the field theory, could be regarded as a singularity in the energy field.

Indeed, equations (1) and (2) provide some fundamental steps into such an investigation and, no matter what the inputs are, the output is always nothing. In theory, the absorber could neutralize any power as if some ways of signal conversion were applied. The recommendation is to make as many experimental attempts as possible since their results will help defense industry on its way to produce something that will truly work in practice. As mentioned before, binary algebra deals with two basic states like quantum physics, so in other words – maybe a Boolean analysis can be used for future research and modelling in that area of science.

The real impact of this article will be described under this chapter as it is needed to introduce a completely new approach to binary logics as a fragment of mathematics that needs to deal with some practical applications as well as with a much deeper understanding of its theoretical paradigms. Further, this chapter will introduce how the binary functions can be presented in a set of real numbers making a comparative analysis of the input and output energetic fields. Everything will be illustrated in the 2-D and 3-D coordinate systems trying to encourage prospective researchers to give their contributions. It will be also explained how the previous mathematical models could be transferred in a set of real numbers not giving any analytics of the

transitional function that could project the elements of the binary logics set into the set of real numbers. For such scientific research it may be necessary to gather a multidisciplinary expert team who would work on such a project for a longer period of time.

Indeed, it is well-known that if equations (1) and (2) are dealt with in the binary set of numbers, such a correlation can give an equation in the real set of numbers as follows:

$$B = A \cdot (1 - A) \tag{5}$$

where:

A - is an input signal in affirmation that is multiplied with its negation;

$1 - A$ - is an inverted input signal that is a negation of the input A which is in the sense of Boolean algebra illustrated as $\overline{A}$; and

B - is an output signal that is a product of affirmation and negation being brought at the inputs.

In any case, the output of equation (5) is 0 which can be described with the truth table as follows:

Table 3 – Truth table of the static absorber
Таблица 3 – Таблица истинности статического абсорбера
Табела 3 – Истинитосна тебела статичког апсорбера

A	1-A	B
0	1	0
1	0	0

As illustrated in Table 3, for $A, B \in \square \wedge A, B \in \{0, 1\}$, it has been feasible to prove that if the binary values have been taken for the inputs and the output, the result will always be a neutralized function that can be graphically represented in a set of real numbers $\square$ via the graph made in the 2-D and 2-D form using the 3D Grapher tool. These illustrations have been provided in the figures as follows.

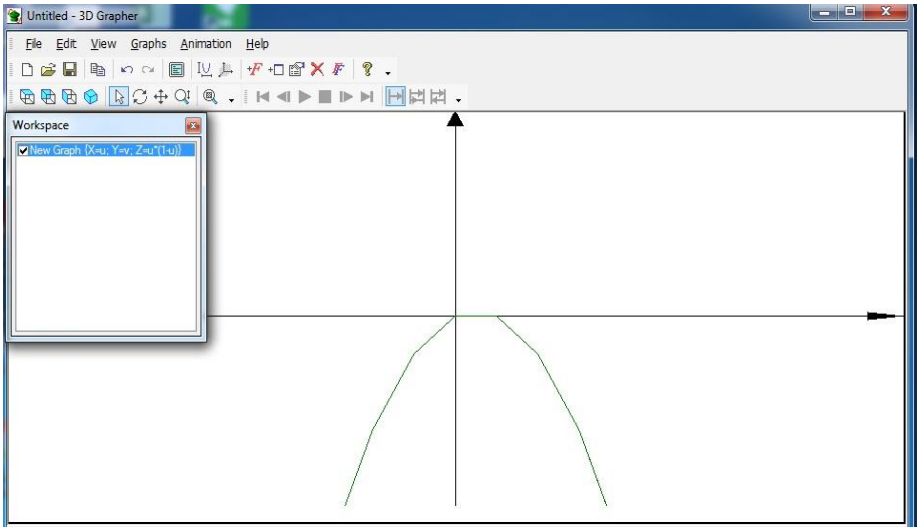


Figure 3 – 2-D graph of equation (5)
Рис. 3 –2-Д график уравнения (5)
Слика 3 – 2-Д графика једначине (5)

Figure 3 shows how equation (5) behaves in the 2-D coordinate system indicating that it is about the square function if $A, B \in (-\infty, +\infty)$.

In other words, in such a case, it is possible to compare a correlation between the input and output signals which can be voltage dealing first, with the values 0 V and 5 V as well as the rest of taken variables.

The next illustration in the 3-D surrounding suggests how input and output voltages are dependable on each other. The graphical representation is given in Figure 4 as follows.

Figures 3 and 4 give a closer insight into how equation (5), being the square function in a set of real numbers, behaves in the 2-D and 3-D space. If singular dots behave like a sink in this case, it is quite clear they can be analyzed as a curve as well as an entire surface in the 3-D environment. As explained through this chapter, the AND logic function in Boolean algebra can be represented as a product in a set of real numbers.

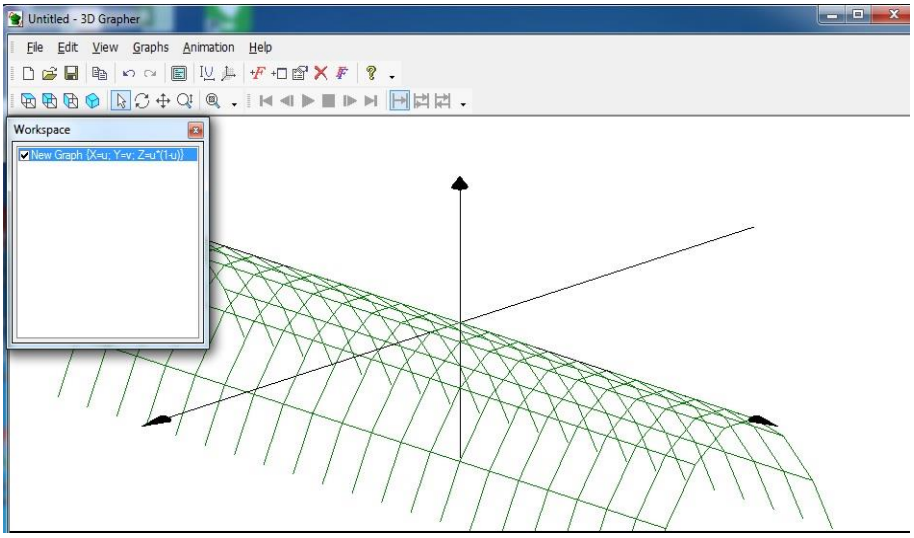


Figure 4 – 3-D drawing of the singularity surface
Рис. 4 – 3-Д рисунок сингулярной поверхности
Слика 4 – 3-Д цртеж сингуларне површине

On the other hand, signals in affirmation and negation are given as described in equation (5). 3D Grapher software deals with the X-Y-Z coordinate system and in this case it is given that X=u, Y=v, and Z=u*(1-u). De facto, the true correlation between the inputs and the output would be X=u, Y=1-u, and Z=u*(1-u). That means only in such a case it is possible to analyze the behavior of the inputs regarding the outputs.

At this stage, it is sufficient to demonstrate the feasible singularity objects as practically there is only one input being either in affirmation or negation and its unique output deals as given above. The advice for future research is to make an attempt to compare input and output voltages in order to realize how they depend on each other and why such an energetic field neutralizes anything getting close to it.

Further, it is significant to introduce the behavior of equations (3) and (4) in a set of real numbers. Their mathematical model is provided in equation (6) as follows:

$$C = A \cdot (1 - A) + B \cdot (1 - B) \tag{6}$$

where:

A - is an input which is multiplied with its negation being $(1-A)$ in which case these two inputs give some product as a result;

B - is an input which is multiplied with its negation being $(1-B)$ in which case these two inputs give some product as a result; and

C - is an output of the big function which is in this case a sum of the variables mentioned above.

The truth table of equation (6) is illustrated in Table 4 as follows.

Table 4 – Proof of equation (6) in the truth table
Таблица 4 – Доказательство уравнения (6) в таблице истинности
Табела 4 – Доказ једначине (6) у истинитосној табели

A	B	C
0	0	0
0	1	0
1	0	0
1	1	0

Apparently, it is necessary to illustrate, using 3D Grapher, how equation (6) deals in the 2-D and 3-D space leaving to other researchers to examine the behavior of the input and output energetic fields. At this level, it is enough to demonstrate such a behavior only in the sense of the X-Y-Z coordinate system. The illustration in the 2-D form is given in Figure 5 as follows.

In this case, the 3D Grapher mathematical model includes two inputs and only one output whose correlations are given in Figures 5 and 6. The model is as follows X=u, Y=v, and Z=u*(1-u)+v*(1-v) which can be assumed as a singular area seeking to be better investigated. In total, some initial ideas are given through this effort and there is a huge task for researchers, engineers, and scientists to develop more superior findings for the entire defense industry.

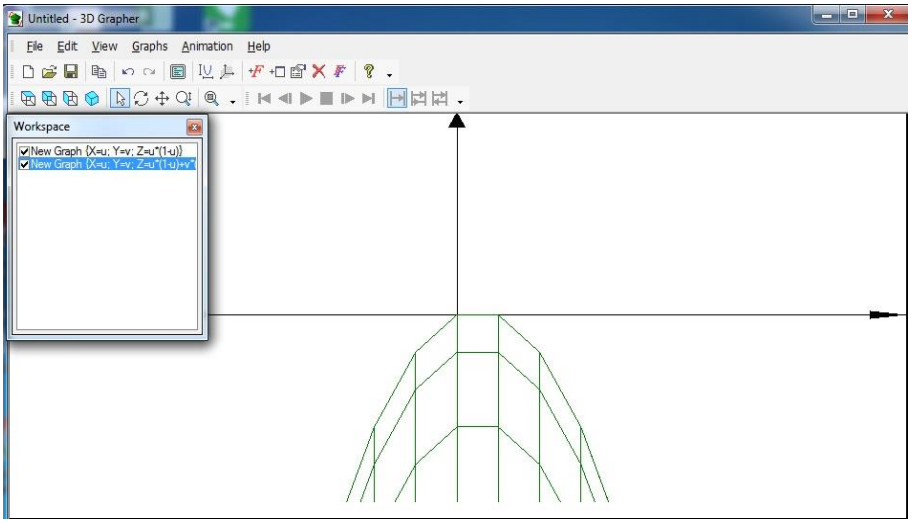


Figure 5 – 2-D behavior of equation (6)
Рис. 5 – 2-Д поведение уравнения (6)
Слика 5 – 2-Д понашање једначине (6)

On the other hand, the 3-D variation of equation (6) is given in Figure 6 as follows.

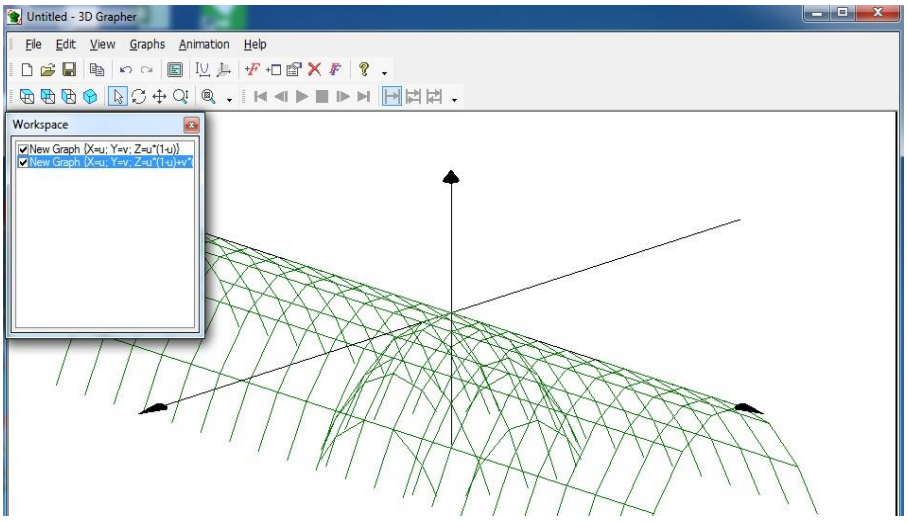


Figure 6 – 3-D graph of equation (6)
Рис. 6 – 3-Д график уравнения (6)
Слика 6 – 3-Д графикон једначине (6)

Applications in cyber industry

As it is well known, one of the biggest applications of Boolean algebra is within digital systems and their electronics. The overall computer science and engineering area relies on that mathematical landscape. One of the worst nightmares for any IT security professional is a breach into some IT infrastructure as that can mean loss of data, sabotage or espionage. Entire teams of cyber analysts have been employed 24 hours a day, 7 days a week in order to discover and terminate any attempt to break into protected networks and establish communication between them and the hacker's workstation. (Djekic, 2021f), (Djekic, 2019), (Djekic, 2020a)

The point is, these professionals will need to manage their surveillance capacities and disconnect manually any attempt of a breach. This is called a good incident response. In other words, monitoring software can recognize any anomalies in the cyberspace, but the incident response is not very effective as it is needed to be done manually. The idea of this research effort is to suggest that the effectiveness of the incident response could be improved by simply passing untrusted traffic through a static absorber and terminating it subsequently. The neutralizer would in such a case reject anything being unwanted and the total incident response could take only a few moments. The basic theory of such a concept is given in this paper and if the idea passes some deeper analyses it could find its place in practice. At this stage, it is sufficient to be aware of such simple, but yet powerful abilities of binary numbers.

Conclusion

This paper discusses some possible capabilities of binary logics suggesting that a static absorber already has some initial modelling, while its dynamic version is still under development. The results given here can trigger an entirely novel research stream when these ideas become empirically verified. Finally, humankind has a skill to handle such superior technology, but the message is to be responsible while doing so.

References

Djekic, M. 2017. *The Internet of Things: Concept, Application and Security*. LAP LAMBERT Academic Publishing. ISBN-13: 978-6202096294.

Djekic, M. 2019. The Informant Task. *Asia-Pacific Security Magazine*, 19 November [online]. Available at: https://www.asiapacificsecuritymagazine.com/the-informant-task/ [Accessed: 1 November 2021].

Djekic, M. 2020a. The Importance of Communication in Investigations. *International Security Journal*, 12 November [online]. Available at: https://internationalsecurityjournal.com/communication-in-investigations/ [Accessed: 1 November 2021].

Djekic, M. 2020b. Detecting an Insider Threat. *Cyber Security Magazine*, 4 June [online]. Available at: https://cybersecuritymagazine.com/detecting-an-insider-threat/ [Accessed: 1 November 2021].

Djekic, M. 2021a. The Digital Technology Insight. *Cyber Security Magazine*, 10 October [online]. Available at: https://cybersecuritymagazine.com/the-digital-technology-insight/ [Accessed: 1 November 2021].

Djekic, M. 2021b. Smart Technological Landscape. *Cyber Security Magazine*, 26 October [online]. Available at: https://cybersecuritymagazine.com/smart-technological-landscape/ [Accessed: 1 November 2021].

Djekic, M. 2021c. Biometrics Cyber Security. *Cyber Security Magazine*, 26 October [online]. Available at: https://cybersecuritymagazine.com/biometrics-cyber-security/ [Accessed: 1 November 2021].

Djekic, M. 2021d. Channeling as a Challenge. *Cyber Defense Magazine*, 17 February [online]. Available at: https://www.cyberdefensemagazine.com/channeling-as-a-challenge/ [Accessed: 1 November 2021].

Djekic, M. 2021e. Communication Streaming Challenges. *Cyber Defense Magazine*, 16 January [online]. Available at: https://www.cyberdefensemagazine.com/communication-streaming-challenges/ [Accessed: 1 November 2021].

Djekic, M. 2021f. Offense Sharing Activities in Criminal Justice Case. *Cyber Defense Magazine*, 13 September [online]. Available at: https://www.cyberdefensemagazine.com/offense-activities/ [Accessed: 1 November 2021].

Đekić, M. 2021. *The Insider's Threats: Operational, Tactical and Strategic Perspective*. LAP LAMBERT Academic Publishing. ISBN-13: 978-620-3-20063-8.

МОДЕЛИРОВАНИЕ СТАТИЧЕСКОГО АБСОРБЕРА

Милица Д. Джекич
независимый исследователь, г. Суботица, Республика Сербия

РУБРИКА ГРНТИ: 27.00.00 МАТЕМАТИКА:
27.43.17 Математическая статистика
20.00.00 ИНФОРМАТИКА:
20.23.25 Информационные системы с базами знаний
78.00.00 ВОЕННОЕ ДЕЛО:
78.21.49 Военная электроника и кибернетика
ВИД СТАТЬИ: предварительное сообщение

Резюме:

Введение/цель: В данной статье будет представлен анализ статического абсорбера, который способен нейтрализовать любой сигнал как в физической, так и в виртуальной плоскостях.

Методы: Используемый в статье подход включает в себя исключительно научные рассуждения, а также модель с ее объяснениями, которые были внимательно проанализированы и оценены с помощью высокоразвитых вычислительных инструментов для проектирования и моделирования. Эмпирические результаты к статье не прилагаются, а только утверждения с их доказательствами.

Результаты: Значимым результатом данного исследования является совершенно новый подход к двоичным системам, которые в данном исследовании связаны со множеством действительных чисел.

Выводы: Цель данного исследования заключается в представлении совершенно новой концепции, которая может быть использована в кибериндустрии, в то время как динамический вариант абсорбера все еще находится в стадии разработки.

Ключевые слова: высокотехнологичная безопасность, знания, статический абсорбер, отклонение сигналов, хакерские атаки, сингулярность, математическое моделирование.

МОДЕЛОВАЊЕ СТАТИЧКОГ АПСОРБЕРА

Милица Д. Ђекић
независни истраживач, Суботица, Република Србија

ОБЛАСТ: бинарна логика, примењена математика, информатика, наменска индустрија, рачунарство, електроника
ВРСТА ЧЛАНКА: претходно саопштење

Сажетак:

Увод/циљ: Статички апсорбер, чија анализа ће бити приказана у овом раду, у стању је да неутрализује сваки сигнал у физичкој или виртуелној равни. .

Методи: Представљено је искључиво научно размишљање и модел са објашњењима која су пажљиво евалуирана коришћењем софистицираних рачунарских алата за пројектовање и симулацију. Емпиријски резултати нису приложени, већ само тврдње са њиховим доказима.

Резултати: Најзначајнији резултат овог истраживања јесте потпуно нови приступ бинарним системима који су овде повезани са скупом реалних бројева.

Закључак: Сврха овог истраживања јесте да представи потпуно нови концепт који може да се користи у сајбер индустрији, док је динамичка варијанта апсорбера још увек у фази развоја.

Кључне речи: високотехнолошка безбедност, сазнања, статички апсорбер, одбијање сигнала, хаковање, сингуларност, математичко моделовање.

Paper received on / Дата получения работы / Датум пријема чланка: 03.11.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 03.01.2022.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 04.01.2022.

ПРЕГЛЕДНИ РАДОВИ

ОБЗОРНЫЕ СТАТЬИ

REVIEW PAPERS

BETA FUNCTIONS IN THE QUANTUM FIELD THEORY

Nicola Fabiano

University of Belgrade, “Vinča” Institute of Nuclear Sciences - Institute of National Importance for 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/vojtehg70-32131;https://doi.org/10.5937/vojtehg70-32131

FIELD: Mathematics

ARTICLE TYPE: Review paper

Abstract:

Introduction/purpose: The running of the coupling constant in various Quantum Field Theories and a possible behaviour of the beta function are illustrated.

Methods: The Callan–Symanzik equation is used for the study of the beta function evolution.

Results: Different behaviours of the coupling constant for high energies are observed for different theories. The phenomenon of asymptotic freedom is of particular interest.

Conclusions: Quantum Electrodynamics (QED) and Quantum Chromodinamics (QCD) coupling constants have completely different behaviours in the regime of high energies. While the first one diverges for finite energies, the latter one tends to zero as energy increases. This QCD phenomenon is called asymptotic freedom.

Key words: Quantum Electrodynamics, Quantum Chromodynamics, Quantum Field Theory, renormalization group, beta function.

Fixed points

In (Fabiano, 2021) we have seen how a generic coupling constant behaves at different renormalisation scales. It should be remarked that this result is valid also for different renormalisation schemes, not only for dimensional regularisation. In this sense the coupling constant is a func-

tion depending on the energy scale μ, and is often regarded to as *running coupling constant*. Just for the sake of simplicity define the new variable $t = \log \mu$ (the t variable could be also thought of as a "time" parameter). With this position, the Callan–Symanzik equation (Callan, 1970; Symanzik, 1970) could be rewritten in a nicer form as:

$$\frac{dg}{dt} = \beta(g) \ , \tag{1}$$

which is a differential equation governing the behaviour of the coupling constant g upon the energy scale considered. As such it also needs some initial conditions in order to be solved – a Cauchy problem. The points $\overline{g}$ for which

$$\beta(\overline{g}) = 0 \tag{2}$$

are called *fixed points* (Symanzik, 1971), and once the coupling g reaches one of these points, it does not evolve anymore. In Fig. (1) a possible scenario for the β function is shown. The origin 0, the points g_1 and g_2 are fixed points. If for the initial scale $t = 0$ the coupling constant g is at one of these points, then it will remain there for any energy scale considered (or "forever", depending on the language one prefers).

There are different kinds of fixed points. Consider the point g_1 and its neighbourhood. From the Figure, for $0 < g < g_1$, $\beta(g) > 0$ then the coupling constant increases with the scale because of eq. (2) (i.e. $dg/dt > 0$), moving towards g_1 for $t \to +\infty$. On the contrary, in the interval $g_1 < g < g_2$ the β function is negative, so the coupling constant decreases and approaches again g_1 as $t \to +\infty$. We conclude that g_1 is a stable fixed point, as g tends to it from either side. It is called the *ultraviolet stable fixed point* - the term "ultraviolet" is present because $g \to g_1$ as $t \to +\infty$.

On the other hand, for the points 0 and g_2 it is clear that the inverse of the previous argument holds true: the coupling g "escapes" from them as $t \to +\infty$, and approaches them as energy decreases, for $t \to 0$. Such points are named the *infrared stable fixed points*.

It is important to know that the fixed points of the β function are difficult to calculate because they are usually determined by nonperturbative effects, apart from the trivial zero at the origin, for $g = 0$.

Behaviour of β function

We shall consider some possible asymptotic behaviours of the β function for energy scale $\mu \to +\infty$. The exact problem we consider is given

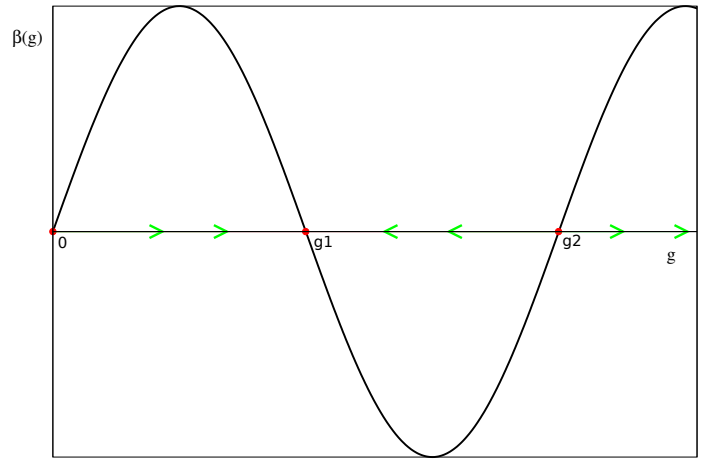


Figure 1 – The Beta function with fixed points 0, g_1 *and* g_2. *The arrows indicate the direction of the flow of g with increasing scale* μ
Рис. 1 − Бета-функция с фиксированными точками 0, g_1 *и* g_2. *Стрелки указывают направление потока g с увеличением шкалы* μ
Слика 1 – Бета функција са фиксним тачкама 0, g_1 *и* g_2. *Стрелице показују правац тока g са повећањем скале* μ

by

$$\mu \frac{dg}{d\mu} = \beta(g)$$
$$g(\mu_0) = g_0 \ , \tag{3}$$

whose formal solution is written as

$$\int_{g_0}^{g} \frac{\mathrm{d}g}{\beta(g)} = \log\left(\frac{\mu}{\mu_0}\right) \ . \tag{4}$$

Different behaviours of the β function are shown in Fig. 2.

For such functions, the running coupling constant g will, for different cases:

(a) approach infinity for a finite value of g, with $\beta(g) > 0$

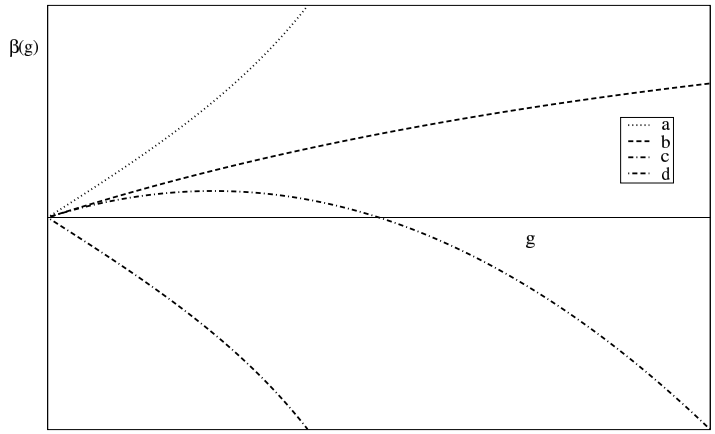


Figure 2 – Beta functions with different asymptotic behaviour
Рис. 2 − Бета-функции с различным асимптотическим поведением
Слика 2 – Бета функције с различитим асимптотским понашањем

(b) approach infinity as $g \to +\infty$

(c) have a finite fixed point in g_1, $\beta(g_1) = 0$

(d) approach $-\infty$ for increasing g, with $\beta(g) < 0$.

Case (a)

Suppose that $\beta(g)$ grows sufficiently rapidly in such a manner that the integral of eq. (4) converges (for instance, any power of g larger than 1), namely

$$\int^{+\infty} \frac{\mathrm{d}g}{\beta(g)} < +\infty \,, \tag{5}$$

then it is clear that the scale μ has a finite upper bound $\mu_{+\infty}$ corresponding to the coupling $g = +\infty$ given by the relation

$$\mu_{+\infty} = \mu_0 \exp\left(\int_{g_0}^{+\infty} \frac{\mathrm{d}g}{\beta(g)}\right) \,. \tag{6}$$

We have already encountered such behaviour, for the QED coupling case as discussed in (Fabiano, 2021), where $\beta(g) = g^3/12\pi^2$ and $\mu_{+\infty}$ is given by the Landau pole (Landau et al, 1954; Landau & Pomeranchuk, 1955) of eq. (40) in (Fabiano, 2021).

Another example is the scalar field theory with the interaction term $g\phi^4/4!$ given by the Lagrangian

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - \frac{m^2}{2!}\phi^2 - \frac{g}{4!}\phi^4 \,, \tag{7}$$

for which the β function is

$$\beta(g) = \frac{3g^2}{16\pi^2} - \frac{18}{3}\frac{g^3}{(16\pi^2)^2} + \mathcal{O}(g^4) \,. \tag{8}$$

The Lagrangian (7) is almost the same of the Higgs field in the Standard Model (Glashow, 1959; Salam & Ward, 1959; Weinberg, 1967). The only difference, yet an essential one, is that in the latter case the scalar field is coupled to fermion fields ψ via a term $\lambda\overline{\psi}\phi\psi$, so called Yukawa coupling (Yukawa, 1935), where λ is another coupling constant different from g.

Using only the first term of eq. (8), we arrive at the expression

$$g = \frac{g_0}{1 - \frac{3}{16\pi^2} g_0 \log\left(\frac{\mu}{\mu_0}\right)} \,, \tag{9}$$

which has the same form of eq. (39) in (Fabiano, 2021) as anticipated; it has also a pole for $\mu = \mu_0 \exp(16\pi^2/(3g_0))$.

Case (b)

The integral of eq. (5) diverges. It means that the coupling constant g becomes infinite only at an infinite energy scale, $\mu = +\infty$. For instance, assume that $\beta(g) = ag^k$, with $a > 0$ and $k < 1$ but $k \neq -1$ - then one obtains for eq. (3) the solution

$$g = \left[g_0^{1-k} + a(1-k)\log\left(\frac{\mu}{\mu_0}\right)\right]^{1/(1-k)} \,. \tag{10}$$

The growth of g in μ is very slow, but in the very high energy limit the coupling becomes independent from the initial condition g_0.

Case (c)

We encounter a fixed point like previously discussed in the section Fixed points for the ultraviolet fixed point g_1, that is $\beta(g_1) = 0$. The β function stays positive for $0 < g < g_1$ and turns negative afterwards. Either if the initial condition g_0 is such that $g_0 < g_1$ or $g_0 > g_1$ the coupling constant g will evolve towards the fixed point, $g \to g_1$ as $\mu \to +\infty$.

Assuming that the root of β in g_1 is simple, then

$$\beta(g) = a(g_1 - g) \text{ for } g \to g_1 \tag{11}$$

with $a > 0$. The solution to eq. (3) is then

$$g_1 - g \sim \mu^{-a} \tag{12}$$

with the assumption that $g_0 < g$, $g_0 < g_1$ and $g < g_1$.

It is worth noticing that we have already discussed a case in which, apparently, an ultraviolet fixed point is obtained. The ϕ^4 scalar theory presents such a point. From eq. (8) one computes the fixed point g_1 as

$$g_1 = 8\pi^2 \, , \tag{13}$$

which, however, has a huge value of $g_1 \approx 80$ thus spoiling the perturbation theory as $g \gg 1$. As the β functions that have been encountered so far have been computed using only the perturbation theory, it is clear that the result obtained above is invalid. The discussion regarding eq. (8) proves the statement of the section Fixed points, for which a fixed point could be basically only computed by means of nonperturbative techniques.

Case (d)

So far, all β functions discussed were positive at least for small positive g, so the renormalisation group flow drives away $g(\mu)$ from the origin $g = 0$. Now suppose that $\beta(g) < 0$ for small positive g, like

$$\beta(g) = -ag^n \, , \tag{14}$$

where $a > 0$, $n > 1$ and an integer. The solution to eq. (3) is then written as

$$g = \frac{g_0}{\left[1 + g_0^{n-1}(n-1)a \log\left(\frac{\mu}{\mu_0}\right)\right]^{1/(n-1)}} \, . \tag{15}$$

A dramatic difference between this and the previous cases is that, for large energy scales, the coupling constant vanishes, i.e.

$$g = 0 \text{ for } \mu \to +\infty \,. \tag{16}$$

This phenomenon is called *asymptotic freedom* (Gross & Wilczek, 1973; Politzer, 1973). With growing energy, the theory has a weaker coupling constant, approximating a free theory, i.e. one without interactions. So at larger energy scales, the perturbation theory gives better results. Remember actually that corrections C of any kind (propagator, coupling, etc.) are computed as series of powers of g,

$$C = \sum_n c_n g^n \tag{17}$$

and this formal series is supposed to converge for small g.

A toy model that exhibits asymptotic freedom could be obtained from the Lagrangian (7) with a negative potential[1] $-g\phi^4/4!$. Its β function has the form

$$\beta(g) = -\frac{3}{16\pi^2} g^2 \tag{18}$$

for which

$$g = \left[\frac{3}{16\pi^2} \log\left(\frac{\mu}{\mu_0}\right)\right]^{-1} \text{ for } \mu \to +\infty \,. \tag{19}$$

i.e. g goes to zero at logarithmic speed.

A very important class of theories that have the property of asymptotic freedom is the Yang–Mills theory (Yang & Mills, 1954), with the gauge group $SU(N)$. Of particular relevance is one of them, quantum chromodynamics – QCD – that is the theory of strong interactions embedded in the Standard Model, whose gauge group is $SU(3)$.

The QCD Lagrangian is written as

$$\mathcal{L} = \overline{\psi}_j \left[i(\gamma^\mu \mathcal{D}_\mu)_{jk} - m\delta_{jk}\right] \psi_k - \frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a \tag{20}$$

where $\psi_j(x)$ is the j–th quark field, indexed by j, k; A^a_μ are the gluon fields, $a = 1 \ldots 8$. γ^μ are the usual Dirac matrices, the covariant derivative is given

[1] We neglect the fact that this theory is ill–defined and that the perturbation theory cannot be applied.

by $\mathcal{D}_\mu = \partial_\mu - igA^a_\mu T^a$. $G^a_{\mu\nu}$ is the gluon field strength tensor, similar to the $F_{\mu\nu}$ electromagnetic tensor, defined by

$$G^a_{\mu\nu} = \partial_\mu A^a_\nu - \partial_\nu A^a_\mu + g f^{abc} A^b_\mu A^c_\nu \tag{21}$$

where f^{abc} are the structure constants of $SU(3)$, $[T^a, T^b] = if^{abc}T^c$, with T^a being generators of the group.

For a generic $SU(N)$ the Yang–Mills theory coupled to fermions the β function at one–loop level is given by

$$\beta(g) = -\frac{g^3}{4\pi^2}\left(\frac{11}{12}N - \frac{1}{3}C_2\right) + \mathcal{O}(g^5)\ , \tag{22}$$

and for the QCD case $C_2 = n_f/2$,

$$\beta(g) = -\frac{g^3}{8\pi^2}\left(\frac{11}{2} - \frac{n_f}{3}\right) + \mathcal{O}(g^5)\ , \tag{23}$$

where n_f is the number of quark flavours with masses much lower than the energy scale considered μ, which can be considered massless.

Defining the QCD strong coupling constant $\alpha_s = g^2/4\pi^2$ in an analogous fashion to QED, where $\alpha = e^2/4\pi$, we obtain from eq. (49) in (Fabiano, 2021)

$$\alpha_s(\mu) = \frac{12\pi}{(33 - 2n_f)\log(\mu/\Lambda)} \tag{24}$$

which exhibits asymptotic freedom as far as the number of quark flavours is $n_f < 17$. Another property due to the presence of (approximately) massless particles is that a dimensionless coupling g_0 is exchanged for a dimensionful parameter Λ, which is an integration constant with dimensions of energy. This phenomenon is referred to as *dimensional transmutation* (Coleman & Weinberg, 1973; Weinberg, 1973). The β function eq. (24) is known today to four–loop order $\mathcal{O}(\alpha_s^4)$, with three and four–loop coefficients being renormalisation scheme dependent. The measured value of a strong coupling constant at the Z peak is

$$\alpha_s(m_Z) = 0.1197 \pm 0.0016\ , \tag{25}$$

while the corresponding value of Λ is about 0.2 GeV.

A few remarks are in order. In the 1950s, Landau argued that in QED the increasing powers of logarithmic terms, that we already encountered at

one–loop level in (Fabiano, 2021), of the form $\log(E/M)$, would coalesce and give raise to singularities for finite values of the energy E. This is the (a) case, with the Landau poles, also known as the *Landau ghosts* or the *Moscow zero* (because $e_0/e(\mu) = 0$), discovered by himself (Landau et al, 1954; Landau & Pomeranchuk, 1955). This argument does not rule out the cases (b) or (c), though. This possible inconsistency in the renormalisation procedure has not yet been proved but it is believed to actually exist.

Today, there is a broad agreement on the fact that the interacting field theories like QED or scalar ϕ^4 we have discussed (which are not asymptotically free) are not mathematically consistent. About QED, there is some evidence against the case (c) with a finite fixed point that would be only possible in the presence of yet unknown nonperturbative effects. However, even if (c) is ruled out, there still remains the possibility (b) with a fixed point at infinity.

There is an electromagnetic analogy for different behaviours of QED and QCD couplings. In QED, the charge is stronger at shorter distances, i.e. is the vacuum acts like a dielectric medium with a dielectric constant

$$\varepsilon > 1 \, , \tag{26}$$

shielding the charge. Remembering the relation of the relative magnetic permeability μ to the dielectric constant to the speed of light, which in our units is 1,

$$\varepsilon\mu = 1 \, , \tag{27}$$

we have a duality relation. The QED case corresponds to $\mu < 1$, also known as Landau diamagnetism, where charged particles in the medium in response to an external magnetic field generate an opposed magnetic field, a phenomenon seen in superconductors, water, copper, and gold. In QCD, the opposite behaviour is observed: the chromoelectric charge is weaker at shorter distances, so its vacuum is anti screening, with a dielectric constant

$$\varepsilon < 1 \, . \tag{28}$$

The equivalent magnetic permeability is $\mu > 1$, known as Pauli paramagnetism, where the particles tend to align with the external field, as in tungsten, aluminium, or lithium. It has to be stressed that the electromagnetic terminology used for QCD is just an analogy to the QED case: by “the charge” we mean the colour charge, by “the magnetic moment” the colour magnetic moment.

References

Callan, C.G. 1970. Broken Scale Invariance in Scalar Field Theory. *Physical Review D*, 2(8), pp.1541-1547. Available at: https://doi.org/10.1103/PhysRevD.2.1541.

Coleman, S. & Weinberg, E. 1973. Radiative Corrections as the Origin of Spontaneous Symmetry Breaking. *Physical Review D*, 7(6), pp.1888-1910. Available at: https://doi.org/10.1103/PhysRevD.7.1888.

Fabiano, N. 2021. Quantum electrodynamics divergencies. *Vojnotehnički glasnik/Military Technical Courier*, 69(3), pp.656-675. Available at: https://doi.org/10.5937/vojtehg69-30366.

Glashow, S. 1959. The renormalizability of vector meson interactions. *Nuclear Physics*, 10(February–May), pp.107-117. Available at: https://doi.org/10.1016/0029-5582(59)90196-8.

Gross, D.J. & Wilczek F. 1973. Asymptotically Free Gauge Theories. I. *Physical Review D*, 8(10), pp.3633-3652. Available at: https://doi.org/10.1103/PhysRevD.8.3633.

Landau, L.D., Abrikosov, A.A. & Khalatnikov, I.M. 1954. *Dokl. Akad. Nauk SSSR*, 95, 497, 773, 1177 (in Russian).

Landau, L.D. & Pomeranchuk, I.Ya. 1955. *Dokl. Akad. Nauk SSSR*, 102, 489 (in Russian).

Politzer, H.D. 1973. Reliable Perturbative Results for Strong Interactions? *Physical Review Letters*, 30(26) pp.1346-1349. Available at: https://doi.org/10.1103/PhysRevLett.30.1346.

Salam, A. & Ward, J.C. 1959. Weak and electromagnetic interactions. *Il Nuovo Cimento*, 11(4), pp.568-577. Available at: https://doi.org/10.1007/BF02726525.

Symanzik, K. 1970. Small distance behaviour in field theory and power counting. *Communications in Mathematical Physics*, 18(3), pp.227-246. Available at: https://doi.org/10.1007/bf01649434.

Symanzik, K. 1971. Small-distance-behaviour analysis and Wilson expansions. *Communications in Mathematical Physics*, 23(1), pp.49-86. Available at: https://doi.org/10.1007/BF01877596.

Weinberg, S. 1967. A Model of Leptons. *Physical Review Letters*, 19(21), pp.1264-1266. Available at: https://doi.org/10.1103/PhysRevLett.19.1264.

Weinberg, S. 1973. New Approach to the Renormalization Group. *Physical Review D*, 8(10), pp.3497-3509. Available at: https://doi.org/10.1103/PhysRevD.8.3497.

Yang, C.N. & Mills, R. 1954. Conservation of Isotopic Spin and Isotopic Gauge Invariance. *Physical Review*, 96(1), pp.191-195. Available at: https://doi.org/10.1103/PhysRev.96.191.

Yukawa, H. 1935. On the interaction of elementary particles. *Proceedings of the Physico-Mathematical Society of Japan. 3rd Series*, 17, pp.48-75. Available at: https://doi.org/10.11429/ppmsj1919.17.0_48 .

БЕТА-ФУНКЦИИ В КВАНТОВОЙ ТЕОРИИ ПОЛЯ

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: В данной статье представлено, как работает константа связи в различных квантовых теориях поля и возможные модели поведения бета-функции.

Методы: Уравнение Каллана–Симанзика используется для изучения эволюции бета-функции.

Результаты: Наблюдается различное поведение константы связи при высоких энергиях в различных теориях. Особый интерес представляет явление асимптотической свободы.

Выводы: Константы связи квантовой электродинамики (КЭД) и квантовой хромодинамики (КХД) ведут себя совершенно по-разному в режиме высоких энергий. Первая отличается конечной энергией, в то время как вторая стремится к нулю, когда энергия увеличивается. Данное явление КХД называется асимптотической свободой.

Ключевые слова: квантовая электродинамика, квантовая хромодинамика, квантовая теория поля, ренормализационная группа, бета-функция.

БЕТА ФУНКЦИЈЕ У КВАНТНОЈ ТЕОРИЈИ ПОЉА

Никола Фабиано

Универзитет у Београду, Институт за нуклеарне науке ”Винча”- Институт од националног значаја за Републику Србију, Београд, Република Србија

ОБЛАСТ: математика
ВРСТА ЧЛАНКА: прегледни рад

Сажетак:

Увод / циљ: Илустровани су рад константе спреге у разним квантним теоријама поља као и могуће понашање бета функције.

Методе: Калан-Шиманзикова једначина користи се за проучавање еволуције бета функције.

Резултати: Примећено је различито понашање константе спреге за високе енергије за различите теорије. Од посебног интереса је феномен асимптотске слободе.

Закључак: Константе спреге квантне електродинамике (QED) и квантне хромодинамике (QCD) имају потпуно ра зличито понашање у режиму високих енергија. Док се прва разилази за коначне енергије, друга тежи нули како се енергија повећава. Овај феномен QCD назива се асимптотска слобода.

Кључне речи: квантна електродинамика, квантна хромодинамика, квантна теорија поља, ренормализациона група, бета функција.

Paper received on / Дата получения работы / Датум пријема чланка: 05.03.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 30.12.2021.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 31.12.2021.

TRANSMISSION OF Q-SIGNALING BY THE TUNNELING PROCEDURE IN THE AUTOMATIC TELEPHONE NETWORK OF INTEGRATED SERVICES OF THE SERBIAN ARMED FORCES

Slađan M. Svrzić[a], *Yulijan* K. Boyanov[b]

[a] Tesla Systems Ltd, Belgrade, Republic of Serbia,
e-mail: milosavljevic_Svrzić@hotmail.com, **corresponding author**,
ORCID iD: https://orcid.org/0000-0003-4525-9844

[b] "SoftServe", Sofia, Republic of Bulgaria,
e-mail: abagar111@gmail.com,
ORCID iD: https://orcid.org/0000-0001-8765-2439

DOI: 10.5937/vojtehg70-33204; https://doi.org/10.5937/vojtehg70-33204

FIELD: Telecommunications
ARTICLE TYPE: Review paper

Abstract:

Introduction/purpose: To specify the practical application of ECMA-355 and ECMA-336 Standards for Q-SIG tunneling and the implementation of mapping functions via the existing IP (Internet Protocol) network of the Serbian Armed Forces (Intranet SAF), in the Private Automatic Telephone Network SAF (PATN SAF), as the main part of the Private telecommunication-information networks of integrated services SAF (PISN SAF).

Methods: Description of the implemented solution and analysis of the software parameters of the established transmission SIP route, with the display of the results obtained in the fight with jitter and echo in the network.

Results: With such a solution, it was achieved that participants from the peripheral parts of the PISN SAF, which operate on the principle of transmission and circuit switching by TDM (Time Division Multiplexing), can connect with each other via the newly established central IP network SAF (Core network) which operates on the principle of transmission and switching packets with the SIP (Session Initiation Protocol), without losing the functionality of Q-SIG from the framework of the digital telecommunication network of integrated services ISDN (Integrated Services Digital Network).

Conclusion: The article deals with the modern IP PINX (Private Integrated Services Network Exchange) manufactured by Mitel, type MX-ONE Service Node 6.0, which is implemented at the transit level PATN SAF and which successfully implements the process of tunneling Q-SIG through the IP network and the necessary functions for mapping the transmission of tunneled Q-SIG messages and mapping voice (and other audio) information to VoIP (Voice over IP) communication media streams through that network. Also, the basic elements for its software preparation during the introduction of a new SIP route, with a capacity of 30 IP trunks in a transmission beam realized with 100 Mb/s-T Ethernet, are given, and the fight with the present jitter and echo in the network is described. Finally, the paper presents the experience-based values of the parameters for reducing the influence of jitter and suppressing echo.

Key words: PATN SAF, Q-SIG, PISN, IP PINX, MX-ONE, media gateway, media server, tunneling Q-SIG, encapsulation, mapping functions, jitter, echo.

Introduction

The Serbian Armed Forces (SAF) is a specific organization that has its own, modern, functional telecommunications information system (FTIS), for sufficiently fast and quality processing and transmission of accurate and protected information (spoken and non-spoken). In the framework of transmission and switching of this information, the FTIS offers a wide range of modern telecommunication customer services and network services to users in the SAF. For their realization, The FTIS SAF provides stable technical support, not only on TDM (Time Division Multiplexing) but also on a modern IP (Internet Protocol) organized platform.

The FTIS SAF is a functional, integrated telecommunication-information platform, which, in addition to the fixed part, also contains a mobile component of the system (McTIS), primarily intended for communication on the ground and in combat conditions. Therefore - while respecting the complexity of the organization, the achieved degree of technical integration and geographical distribution - the FTIS SAF coincides with the performances, determinants and standards of a large modern CTN (Corporate Telecommunications Network). (Svrzić, 2019; Svrzić et al, 2021)

About 15 years ago, in an important part of the FTIS SAF, i.e. in the Private Automatic Telephone Network SAF (PATN SAF), a network signaling system type Q-SIG (Q-Signalling), oriented to work on CCS (Common Channel Signaling), was put into operation, being specially designed and globally standardized for use in CTN (InterConnect Communication, 1995). Its application, in the PATN SAF, first provided the possibility for ISDN (Integrated Services Digital Network) interoperability between participating Digital Automatic Telephone eXchanges-DATX of different manufacturers. Later, this interoperability was provided between these DATX and the switching centers within the McTIS, as well as the switching center of the Digital Mobile Radio Network TETRA (Terestrial Trunking Radio) (Svrzić & Jovanovski, 2021a; Svrzić et al, 2021b). Also, interoperability with PINX (Private Integrated Services Network eXchange) was provided from PTNs (Private Telecommunication Networks) of other armies or military alliances, with which the interconnection of the FTIS SAF is planned. In the end, of course, that interoperability is provided with the switching nodes of public mobile telephony operators in Serbia. (Svrzić, 2019; Svrzić et al, 2021)

In this way, high integration has been achieved in the PATN SAF to date, both in terms of complete independence from various ISDN DATX manufacturers and in terms of achieving the planned scope of implementation of basic and additional customer services and network services (specified by the whole family of individual Q-SIG standards), which have become available to PATN SAF users, regardless of which network switching node they are connected to. However, the integrated FTIS SAF today, in addition to the TDM PISN (Private Integrated Services Network), also contains the Intranet SAF. The network layer protocol, in that IP network, is defined according to IETF RFC 760 and IETF RFC 791J Recommendations, while on the application layer the network is based on the SIP (Session Initiation Protocol), which is defined according to IETF Recommendations RFC 3261J and IETF RFC 3311. Such heterogeneous situation (existence of TDM and IP) immediately raised the question of the further application of Q-SIG in the PATN SAF, as a large part of the FTIS SAF, in terms of efficiency, economy and comprehensiveness of customer services and network services, not only on its homogeneous ISDN parts but also on parts with transport IP / SIP networks (proprietary IP networks within the Intranet). Also, it raised the question of the possibility of extending the service life of the existing switching equipment (PINX) during the time when the IP

platform will be the dominant medium for signal transmission between them.

For these reasons, in the last few years, a certain number of node and transit DATXs have been completely replaced or modernized in the PATN SAF, which have (of course) become interoperable with the aforementioned proprietary newly built IP network (Intranet SAF). The Intranet SAF offers a packet mode of switching and transmission of all services (without connection) that are based on Internet Protocol, as the mentioned network layer protocol. The newly introduced, modern digital switching systems of Western origin are the so-called IP PINX, which are specially designed to work in the PISN and, using an integrated gateway, enabled to work with both ISDN and IP / SIP environment. At the same time, which is of crucial importance for their application in the PATN SAF, they enable the continuation of the successful functioning of network signaling of the Q-SIG type. Such IP PINXs today play the role of main entities in the PISN SAF, which basically consist of a switching function and a call management function. Of course, they successfully support the networking and implementation of all additional services and ANFs (Additional Network Features) with the application of Q-SIG, not only in accordance with previous Standards: ECMA-142, ECMA-143, ECMA-165 and relevant individual Q-SIG standards from Annex D Reference: “QSIG. The Handbook for Communications Managers” (InterConnect Communication, 1995), (for the PINS part with TDM organized switching and transport network), but also in accordance with new ECMA-355 and ECMA-336 Standards (for the PINS part with IP organized switching and transport network). (Ecma International, 2002; Ecma International, 2008; Svrzić, 2019; Svrzić et al, 2019a; Svrzić et al, 2021; Svrzić & Jovanovski, 2021a)

Role of ECMA-355 and ECMA-336 Standards in the PATN SAF

Let us recall that ECMA-355 Standard specifies a procedure for tunneling Q-SIG messages over the SIP, which is an application layer protocol for establishing, terminating, and modifying multimedia sessions. The SIP is usually transmitted over the IP, as a network layer protocol, so in this case phone calls are considered a type of multimedia session in which only audio signals are exchanged. Namely, in the real telecommunication network scenario SAF, the application of ECMA-355 Standard solves the case where a Q-SIG call (or only signaling independent of the call), which originates from the "A" user connected to

PINX from some TDM part of the PISN, passes through the central works with the IP network using the SIP, and ends with “B” of the user connected to the PINX from another TDM part of the PISN (or another PINX of the same TDM part of the PISN). It is very important to emphasize that during such a way of connecting, they manage to preserve all the possibilities of Q-SIG during the passage through the IP network. The reason for this is that by applying the Q-SIG tunneling procedure, its original messages are encapsulated within SIP requests and SIP responses, which are exchanged in the context of the prescribed SIP dialogue in the IP network. This then means that, by applying the tunneling procedure for the transmission of signaling messages from the Q-SIG, in the PATN SAF it is possible to call between PINX, i.e. "islands" within the parts of the PISN with circuit switching that use Q-signaling, and in the event that their interconnection (in one part) is realized by a transport IP network (which uses the SIP), without losing Q-SIG functionality. In such situations, PINX provides its participants with a regular Q-SIG call, or a Q-SIG call by type with independent signaling, as well as additional services and all ANFs, as the applied innovated ECMA-355 Standard facilitates the introduction of improved SIP and SDP functionality (Session Description Protocol, defined by IETF Recommendation RFC 3264J). These improvements are of such a nature that they include the possibility of applying encryption of useful signals and mechanisms for more functional exchange of information (offers and responses) within the SDP, which (among other things) include mandatory renegotiation (i,e. negotiation and vice versa) during the exchange of SDP offers/responses on the part of the connection path with the IP network. (Ecma International, 2008; Svrzić, 2019; Svrzić et al, 2021; Svrzić & Jovanovski, 2021a)

In order to more precisely define the role of ECMA-355 Standard, which addresses the issue of modernized use of Q-SIG in the heterogeneous PATN SAF, it should be noted that it covers only the case of this type of connection in which an individual dialogue between two Gateways (edge IP PINX located at both ends of the transport IP network) is used to make one regular Q-SIG call (or one call-independent signaling connection), basically as defined in ECMA-165. This specifically means that ECMA-355 Standard in the PATN SAF applies only to situations where, on a part of the transport IP network, the SIP dialogue is initiated at the beginning of a regular Q-SIG call (or call-independent signaling) and deleted upon their completion (or interruption). An improved scenario, according to which one SIP dialogue would be maintained in the long run and used for tunneling messages of multiple

Svrzić, S. et al, Transmission of Q-signaling by the tunneling procedure in the automatic telephone network of integrated services of the Serbian Armed Forces, pp.169-206

Q-SIG calls, or multiple connections of independent signaling, with a possibility to accept them at any time (including those calls that are just generated), is not supported in the specifications of the said ECMA standard, so it could not be applied within the PATN SAF. (Ecma International, 2008; Svrzić, 2019; Svrzić et al, 2019a; Svrzić et al, 2021)

The implementation of the mapping functions in the IP switching systems PISN, which are necessary for the use of network intervention scenarios, in the PATN SAF is achieved using ECMA-336 Standard, which is a pragmatic and broad-based consensus for regulating this area of work in the PISN. In fact, this standard specifies functions for using a packet network from an IP framework, as a network layer protocol. In this regard, ECMA-336 Standard specifies how to use the TCP (Transport Control Protocol), as the transport layer protocol defined by IETF Recommendation RFC 761, and the UDP (User Datagram Protocol), Recommendation IETF RFC 768, and to interconnect the two IP PINXs that make up the entities of heterogeneous PTNs (Private Telecommunications Networks), composed of marginal PISNs and central IP networks. The interconnection of the specified IP PINX, connected by the transport IP network, is achieved by transmitting the inter-PINX signaling protocol Q-SIG (as specified in ECMA-143, ECMA-165 and other ECMA standards), directly via TCP, and by transmitting inter-PINX user information (e.g. speech), via the RTP (Real-time Transport Protocol), as defined by IETF RFC Recommendation 1889, whereby the RTP is transmitted within the UDP.

According to ECMA-336 Standard, two types of inter-PINX connection (IPC) of participating IP PINX are envisaged:

• “on demand”, where a separate TCP connection for Q-SIG is established at the beginning of each call and deleted at the end of that call; and

• “semi-permanent”, where one TCP connection with unlimited duration transmits Q-SIG on behalf of multiple individual calls.

To comply with this standard, each IP PINX in the PATN SAF constructively meets the reference configuration defined in ECMA-133 Standard and the requirements set out in the implementation of the Implementation PICS (Conformance Statement Proforma), the text and form of which are defined in the Annex A of ECMA-336 Standard. Their switching and call management functions communicate logically, via the Q point instance, on both connected IP PINXs. This communication is known as an IPL (Inter-PINX link) and contains a signal channel, known as a D$_Q$ channel, and one or more channels for user information, each

known as a Uᵩ channel. One or more IPLs can be established in many ways between the same pair of cooperating IP PINXs. Specifically, in the PATN SAF, some realized IPLs use IP-based IVN (Intervening Network) services. Each IP PINX is physically connected to the IVN at a reference point “C”, and the IVN then provides connections, defined as Inter-PINX connections between the reference points “C” of the end PINXs. This then means that the mapping functions, within each of the IP PINX, map the Dᵩ channel and Uᵩ channels at the reference point “Q” to one or more IPCs, which are then held via the reference points “C”.

In the PATN SAF, where the IVN is IP-based, ECMA-336 Standard is used to specify mapping functions to establish the following types of IPC:

• For a TCP connection, used to transmit Q-SIG signaling messages and RCI (Resource Control Information).

• To establish a pair of UDP streams, one stream in each direction, to transmit user information (audio and others) over the RTP.

Connecting participating IP PINXs means that the IPL requires one TCP connection, to support the Dᵩ channel, and one pair of UDP streams, to support the Uᵩ channels, and a TCP connection (in addition to carrying the Q-SIG protocol) is also required to transmit information on resource control (RCI), which are essential for establishing UDP flows. (Ecma International, 2002; Svrzić, 2019; Svrzić et al, 2019a; Svrzić et al, 2021)

Description of the IP PINX manufacturer MITEL type *MX-ONE Service Node 6.0* from the PATN SAF

In the current PATN SAF, the main representative of the mentioned IP PINX is Mitel's switching system of the type *MX-ONE Service Node 6.0,* which is by nature a SIP Soft Switch for SaaS applications (Software-as-Service). In the PATN SAF, this type of IP PINX was introduced for its modernization, as it provides users with all integrated IP communications services (modern voice and video services and functions), but also, through the integrated Media Gateway (MGW), very successfully enables servicing inherited protocols, services and functions from the framework of TDM and analog technology (Svrzić, 2019; Mitel Sweden AB, 2018a).

Components and architecture of the MiVoice MX-ONE Service Node communication systems

Each *MiVoice MX-ONE Service Node 6.0* switching system consists of the following three main components:

• Telephony Server *MX-ONE Service Node* (formerly known as *MX-ONE Telephony Server*), which has the task of taking care of signaling. It is actually call management software, based on the Novell SUSE® Linux Enterprise Server (SLES) version 11, with a 64-bit codeword architecture. It can be installed on the private IP network itself (or in the Esxi virtual environment on the cloud), as an instance of VMware Virtual Machine, or it can be installed on a standard physical, Intel-based server (i.e. any other server based on Intel technology).

• Software or hardware Media Server *MX-ONE Media Server*, with DSP (Digital Signal Processor) resources for managing tone detection, multiple conferencing and packet switching between different IP endpoints, i.e. between different protocols and codecs (SIP and H.323 protocols; G.711 and G.729 codecs) in a homogeneous SIP environment, when direct media connection is not possible, i.e. when direct exchange of media streams between terminals is not performed. In installations with the SIP environment only, the Media Server has a load distribution/load balancing function and there is no need for dedicated Media Gateway hardware. For such installations, the Media Server can be located in the same Linux machine as the *MX-ONE Service Node* Call Server, which reduces the user trace, but can also be located on a separate server.

• Media Gateway, which is not a mandatory component, but must exist as a supplement to the IP PINX variant in the PATN SAF. It is one or more hardware units, additionally installed in the IP PINX configuration, to provide everything that the Media Server does, but also to provide users with services on physical participant and transmission interfaces in TDM technology, and according to PINX, public networks and auxiliary devices. The Media Gateway also includes DSP resources for tone management, conferencing, packet switching to IP phones (SIP and H.323) and for media conversion between different protocols. Any combination of the Media Server and the Media Gateway (up to a maximum of 15 Media Gateways) can be connected to the same Server to call the *MX-ONE Service Node*.

An overview of the manufacturer's (proprietary) system main components, terminal devices, applications and parts of the IP PINX *MX-ONE Service Node 6.0* IP monitoring and management system, as well as the systems and applications of other manufacturers that can be included in this system, is shown in Figure 1. It should be immediately pointed out (although part of it is not explicitly seen in the Figure) that the IP PINX itself, in addition to the above basic components, also includes hardware components for capacity building of various non-IP participants (analog and digital), components no IP and no ISDN trunks and power supply components. It also includes various terminal devices, which include all types of Mitel's participating telephones (IP, digital, video, mobile DECT, IP DECT, etc., up to analog), Legacy Terminals of earlier generations-LT and intermediary apparatus-AC (Attendant Clients).

The necessary monitoring and management of this system is realized by connecting an external Directory Server which is not a Mitel product, and which then contains all the necessary dedicated, managerial service software (software packages: Provisioning Manager, Service Node Manager, Traffic Manager, etc.). To support the smooth operation of the IP PINX itself and the monitoring and management system, there are all the necessary software applications. Various 3rd Party devices, systems and other applications (from other manufacturers) can be connected to this IP PINX, such as VoIP Recording, SMS Server, Contact Center, Attendant, IPC, etc. (Mitel Sweden AB, 2018a)

For IP PINX, applied in the PATN SAF, Media Gateway LIMs (Line Interface Modules) type *MX-ONE Classic* with an implemented MGU2 board are implemented and housed in 19 '' LIM cabinets type LBP22. In the basic variant (with one MGU2 board) Media Gateway LIM supports up to 4 interfaces of the ISDN/PRA E1 or T1 type, analog and digital extensions, mobile DECT extensions, IP extensions (with H.323 and SIP, including IP DECT and WiFi), IP networking (with H.323 and SIP) as well as Q-SIG networking.

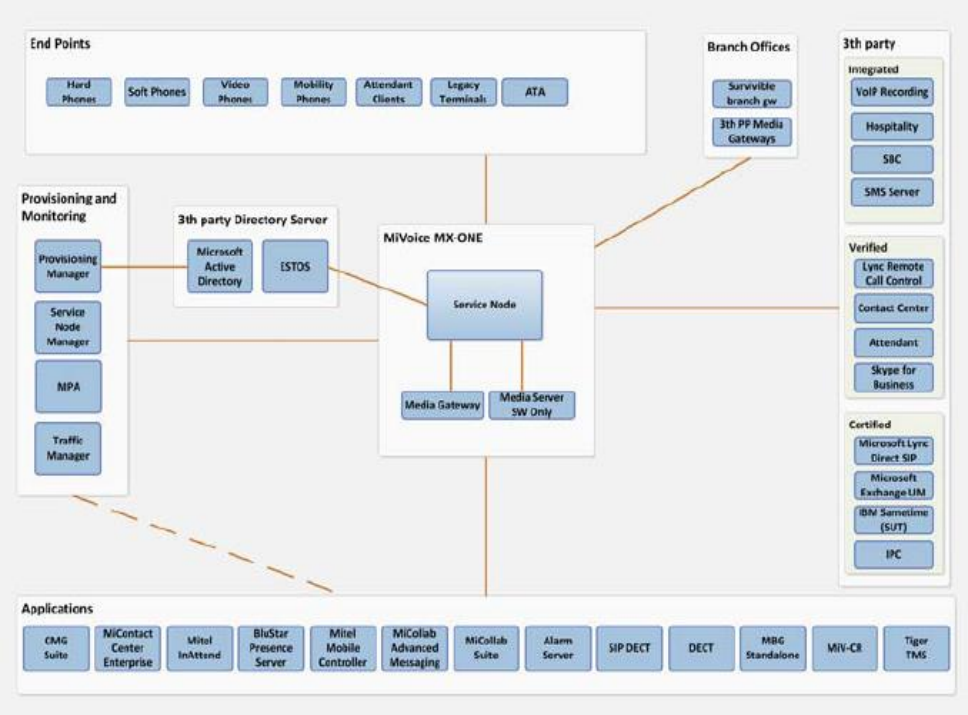


Figure 1 – Overview of the main and additional components, devices and applications of the IP-oriented PINX type MX-ONE Service Node 6.0 (Mitel Sweden AB, 2018a)

Рис. 1 – Обзор основных и дополнительных компонентов, устройств и приложений IP-сервисно-ориентированного узла PINX типа MX-ONE 6.0 (Mitel Sweden AB, 2018a)

Слика 1 – Преглед главних и допунских компоненти, уређаја и апликација IP оријентисане PINX типа „MX-ONE Service Node 6.0" (Mitel Sweden AB, 2018a)

The appearance of a built, modern IP PINX type *MX-ONE Service Node 6.0* on one of the telecommunication centers in the PATN SAF, with the architecture of 2 Media Gateway LIMs in one cabinet, type *MX-ONE Classic* (in the basic variant), is shown in Figure 2 (Svrzić, 2019).

Figure 2 – Appearance of a modern, IP-oriented, transit PINX type MX-ONE Service Node 6.0 at a telecommunications center in the Air Force (Svrzić, 2019)
Рис. 2 – Изображение современного, IP ориентированного, транзитного PINX типа MX-ONE Service Node 6.0 в телекоммуникационном центре Военно-воздушных сил (Svrzić, 2019)
Слика 2 – Изглед савремене, IP оријентисане, транзитне PINX типа „MX-ONE Service Node 6.0" на једном телекомуникационом центру у Ратном ваздухопловству и противваздухопловној одбрани (РВ и ПВО) (Svrzić, 2019)

Figure 3 shows the layout of a 7U cabinet of the Media Gateway LIM, type *MX-ONE Classic* (with the MGU2 board), from the composition of the *MX-ONE Service Node 6.0* (Mitel Sweden AB, 2018a).

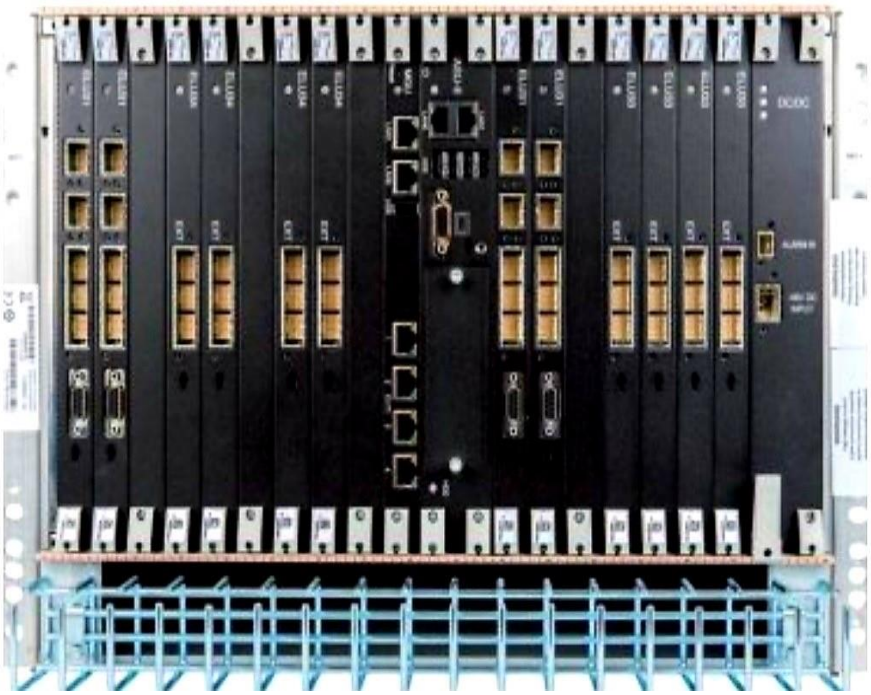


Figure 3 – Appearance of the 7U cabinet of the Media Gateway LIM type MX-ONE Classic (with the MGU2 board) from the composition of the MX-ONE Service Node 6.0 in the PATN SAF (Mitel Sweden AB, 2018a)
Рис. 3 – Изображение шкафа 7U Media Gateway LIM-а типа "MX-ONE Classic (с платой MGU2) из состава сервисного узла MX-ONE 6.0 в PATN Вооруженных Силах Республики Сербия (Mitel Sweden AB, 2018a).
Слика 3 – Изглед 7U кабинета Media Gateway LIM-а типа „MX-ONE Classic" (са плочом MGU2) из састава „MX-ONE Service Node 6.0" у ПАТлМр ВС (Mitel Sweden AB, 2018a)

Basic traffic characteristics and components of the IP PINX system *MX-ONE Service Node 6.0*

Native support for IPv6 addressing

Regarding the *MX-ONE 6.0* version, in addition to (earlier) IPv4, this switching system also supports new IPv6 addressing. The *MX-ONE Service Node* call server and Gateway components can operate as a native IPv6 network, in accordance with IETF Recommendation RFC 2460 (Deering & Hinden, 1998). It is assumed that the HV platform and OS software can work using IPv4/IPv6 "dual stack" interfaces for the IP network. Alternatives are: IPv4/IPv6 “dual stack” or just IPv4. From a signaling and media perspective, the software components of the MX-ONE elements (Call Manager and Media Gateways) can be configured to perform and share standard IPv6 addressing. An IPv4/IPv6 "dual stack" is installed for Inter-server communication, but only IPv6 is used regularly. In fact, the entire system (all servers) must use the same IP version of addressing.

IPv6 and IPv4 addressing are supported for SIP terminals, clients and trunks. According to H.323 terminals, H.323 client and H.323 trunk, only IPv4 addressing system is supported. If one terminal only supports IPv4 and the other terminal only supports IPv6, the call between these two terminals will only be possible with a gateway. The MGU2 and the Media Server support both IPv4 and IPv6 addressing, but, in cases where security (signal encryption) is not used, only the IPv6 addressing variant is used for the MGU2. (Mitel Sweden AB, 2018a)

VoIP protection interfaces, protocols, QoS and telephone applications

The software performs call management functions and has complete control over all ongoing calls as well as resources in the Media Gateway. The following protocols and interfaces are available for the external connection of *MX-ONE Service Node 6.0*, both to systems and applications of the same manufacturer and to systems and applications of other manufacturers ("Third Party"):

- Private networking via SIP trunks as well as via H.323 trunks, where ISDN Q-SIG or proprietary ISDN signaling is transmitted.
- Private networking via E1 (30B + D) and T1 (23B + D) trunks, via ISDN Q-SIG transmission, where T1 is used only in the MGU2.
- Private networking via ISDN trunks E1 and T1, using proprietary signaling.
- Private networking via MFC signaling transmission.
- Private networking via signaling transmission via CAS (Chanel Asotieitid Signalling).

• Private networking via DASS2 signaling transmission.

• Private networking via DPNSS (Digital Private Network System Signaling) and CAS transmission via E1 and T1 trunks.

• Public SIP trunk (with different network operator profiles).

• Public ISDN PRA via E1 and T1 and ISDN BRI (2B + D). (Mitel Sweden AB, 2018a)

When it comes to the quality of service in VoIP, i.e. quality of service - QoS (Quality Of Service), it can be registered upon a call, as follows: delay, jitter, codec used and packet loss rate can be monitored and recorded. The data can be displayed in the Service Node Manage" or via the CIL (Command Line Interface) call log output information.

When it comes to VoIP protection and security, the MX-ONE Service Node supports the use of the SRTP (Security Real-time Transport Protocol), as recommended by IETF RFC 3711 (Baugher et al, 2004). The MX-ONE Service Node also supports TLS (Transport Layared Security), as recommended by IETF RFC 4346/5246 (Dierks & Rescorla, 2006; Dierks & Rescorla, 2008), which provides secure access to IP phones and web services and secure signaling between IP phones and the MX-ONE Service Node. (Mitel Sweden AB, 2018a)

It is quite understandable that the SAF is paying more and more attention to the security aspects of the IP telephony infrastructure, which is also characteristic of the civil sector, where it is taken care of by corporate information directors (CIOs), many IT administrators and users themselves. Voice over IP traffic (signal and media) must be protected from possible numerous attacks. For example: media streams are protected from eavesdropping and intrusion, and signaling from modifications. For this reason, the PATN SAF specifically performs group crypto protection on IP/SIP trunks, which is necessary in order to professionally protect the signaling of VoIP messages and the content of media streams. Regardless of the aforementioned, the MX-ONE Service Node 6.0 system by default supports the following security measures that can be applied in practice:

• Use secured RTP (i.e. SRTP) to protect media streams. MX-ONE supports the use of SRTP to encrypt media streams in IP phones as well as in MGU2,

• Use Transport Layer Security to protect signal messages. In doing so, TLS guarantees the privacy of signaling even when SRTP keys are exchanged between parties, and

• Support a number of flexible security "policies", i.e. support environments with different security requirements. If extensions are

allowed, then the main principle for security policy is guidance: whether these extensions must be registered in the system or not. After the registration of the realized extension, in terms of security, calls to any other party are allowed. SIP terminals must be authenticated using HTTP digest authentication. If the user is assigned a PIN code, authentication will be performed together with the SIP dialog, and from the SIP framework requires "INVITE". MX-ONE servers "spin" on operating systems that are highly capable of successfully resisting the most common network attacks. In that sense, recognized endangered services are immediately turned off, and the integrity of the files is periodically checked. In addition, clients are advised to implement security "policies" that cover the management of "patches" and antivirus software "updates".

To overcome the separation of VLANs, server "farms" need to be protected by "fire walls" and IDSs (Intrusion Detection Systems), which can block attacks. All control interfaces to MX-ONE servers can be run via secure protocols, such as SSH and HTTPS. Management and access operations of such interfaces are logged to have maximum control in the system. Users and system administrators must always authenticate themselves before obtaining permission to access the system. In addition, the access control mechanism allows different levels of privilege roles to be assigned to both users and system administrators. With *MX-ONE 6.0*, VoIP security keys have been modified to comply with EU legislation 388/2012 (formerly 1232/2011). The VoIP security key is only allowed to work in one system installation. (Mitel Sweden AB, 2018a)

Media Server system component on the ASU-E board

From the aspect of the problem of IP PINX networking type *MX-ONE Service Node 6.0* and the application of the Q-SIG tunneling procedure on the part of the central IP network (Core network) from the PTIS SAF, the system components: Media Server (*MX-ONE Media Server* variants) and the Hardware Media Gateway on the MGU2 board are of certain interest.

The Media Server Unit *MX-ONE Media Server* has a Novells SUSE® Linux Enterprise Server (SLES) version 11 operating system, with a 64-bit architecture. In principle, this variant of the Media Server unit can be implemented in several variants, but the IP PINX *MX-ONE Service Node 6.0* in the PATN SAF uses a variant of the ASU-E Media Server board.

The applied variant of the Media Server board type ASU-E is characterized by improved performance and is based on the COMXpress

Svrzić, S. et al, Transmission of Q-signaling by the tunneling procedure in the automatic telephone network of integrated services of the Serbian Armed Forces, pp.169-206

standard. The ASU-E server board is included in the configuration of LIMs of the *MX-ONE Classic* type, in variants with service of one or more Media Gateways. It is the latest server board (which has 16 GB of RAM), so in connection with that, there is a novelty in the IP PINX *MX-ONE Service Node 6.0:*

• 64 bit OS (SLES11) and also natural n + 1 redundancy (network redundancy is not necessary; "Split brain" automatic recovery; controlled return and transition; clusters can be added, removed or reconfigured in the system),

• Support for IPv6 addressing, so all components (Media Server and MGW) must be either IPv4 or IPv6 compatible; support for SIP trunks and SIP extensions; Dual stack is provided; IPv4 translations from/to IPv6 must be performed via MGW,

• Media Server enhancements, which include a mix of Media Servers and MGUs, based on a maximum of 15 MGW per server; increased capacity of 2,000 RTP resources; ~ 50,000 users without using MGW for G.729 Codec (1/10 capacity),

• "Ring groups" that include new items in "Hunt groups" (simultaneous ringing permission for up to 16 users - except DECT); RVA, diversions; Ring and Hunt groups, individual log-in / out; new procedures for "log-on / out" of individual groups,

• Support for CAS extensions on MGU2,

• Support for CAS trunk signaling, and

• VMware certified ASU. (Svrzić, 2019; Mitel Sweden AB, 2018b)

Media Gateway system component on the MGU2 board

The Media Gateway board MGU2 is responsible for reconciling the IP and TDM environment in the IP PINX *MX-ONE Service Node 6.0*, with its specific position in the 7U cabinet, LIM type LBP22, which in practice is recognized by a special connector , as shown in Figure 4.

The main functions of the MGU2 board are as follows:

• Mediate in all communications to the *MX-ONE Service Node*,

• Have interfaces for digital ISDN / PRA trunks E1 / T1,

• Provide RTP / SRTP, DTMF detection, DTMF tones and facsimile tones over RTP and removes jitter on RTP, and echo in VoIP communication,

• Provide T.30 G3 fax transmission using Protocol T.38,

• Realize the reception and sending of DTMF codes for mobile extensions,

• Realize the sending of tones in accordance with the standards of particular countries,

• Provide a conference,
• Provide greeting messages, and
• Provide network redundancy.
• Provides external alarms.

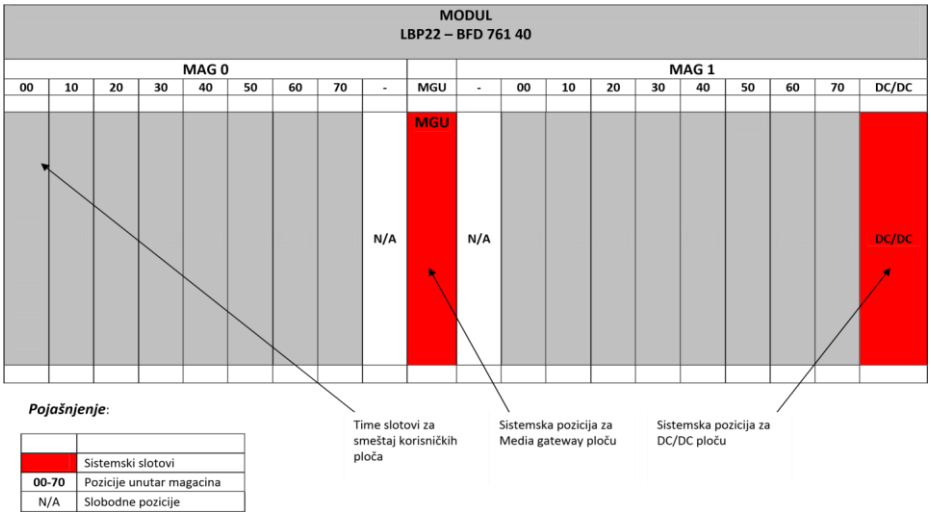


Figure 4 – Appearance of the LIM Media Gateway 7U cabinet type LBP22, with a display of precisely defined positions for the MGU2 board and the DC/DC circuit in it (Mitel Sweden AB, 2017)
Рис. 4 – Изображение шкафа LIM Media Gateway 7U типа LBP22 с отображением точно определенных позиций узлов платы MGU2 и схемы DC/DC преобразователей (Mitel Sweden AB, 2017)
Слика 4 – Изглед LIM Media Gateway 7U кабинета типа LBP22, са приказом тачно дефинисаних позиција за MGU2 плочу и DC/DC склоп у њему (Mitel Sweden AB, 2017)

The layout of the front panel of the Media Gateway MGU2 and an overview of the elements on it are shown in Figure 5.

Also, inside (on the board itself), there is a V24 interface for accessing the board, while on the back of the board there is a Back plane interface that can communicate with 16 position-boards. The displayed LED indication, on the front side of the MGU2 board, indicates the operational states in the operation of the board via visualization, as follows:

• Blinking red - the panel is in “boot mode”,
• Solid red - the board is not active,
• Solid green - the board is registered to MX-ONE as well as its communication ports, and

Svrzić, S. et al, Transmission of Q-signaling by the tunneling procedure in the automatic telephone network of integrated services of the Serbian Armed Forces, pp.169-206

• Flashing green - active board and STCP packets are sent from MX-ONE to MGU2. (Svrzić, 2019; Mitel Sweden AB, 2017)

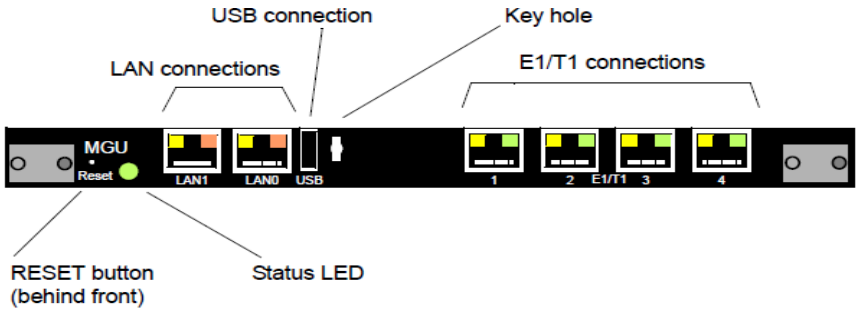


Figure 5 – Appearance of the front panel of the Media Gateway MGU2 (Mitel Sweden AB, 2017)
Рис. 5 – Изображение передней панели Media Gateway MGU2 (Mitel Sweden AB, 2017)
Слика 5 – Изглед фронта плоче Media Gateway-a MGU2 (Mitel Sweden AB, 2017)

MGU2 setting

When initializing the MGU2 board, of course for the role of the Media Gateway in the IP PINX system *MX-ONE Service Node 6.0*, software settings are performed using the following commands:

• "***setpar eth0_ip ip-address/netmask***" - address media_gateway_config,
• "***setpar eth2_ip ip-address/netmask***" - address media_gateway_interface,
• "***setpar def_route ip-address***" - the default Gateway address,
• "***setpar nfs_server ip-address***" - MX-ONE address,
• "***dispar all***" - check parameters,
• "***savepar***" - save parameters, and
• "***restart***" - restart.

Note that in terms of the application of command syntax, in *MX-ONE Service Node 6.0* in CIL, the syntax of MML commands for TDM is retained, as well as the added syntax of new UNIX commands for the IP (these commands have a record in Linux). (Svrzić, 2019; Mitel Sweden AB, 2017)

Reporting the MGW Signaling Interface

The command that defines the applied signaling of the MGU2 Media Gatewey and defines the Signaling interface is:

"***media_gateway_config-i-m1A-mgw-type MGU-cidr 192.168.5.56-default gateway 192.168.5.1***", where the most important parameters are:

• *-cidr* - address of the interface with the network mask in the format X.X.X.X / X,
• *-default-gateway* - gateway address,
• *-ip*-configuration-*mode* (static, dhcp, slaac),
• *-l* - number of sheets,
• *-link-mode* - interface speed,
• *-media-gateway* - number of lim and gateway; format: LG, L = 1-124, G = A-O, and
• *-mgw-type* - type mgw (lsu, mgu). (Svrzić, 2019; Mitel Sweden AB, 2017)

Reporting the MGW RTP interface

The command that defines the RTP data for media streams in the MGU2 Media Gateway and defines the Signaling Interface is:

"***media_gateway_interface-i-media-gateway 1A-cidr 192.168.5.55-default gateway 192.168.5.1***", and the parameters are exactly the same, as well as when registering the Signaling Interface, with the following two parameters:

• *-port-start* and
• *-port-stop*, which defines the range of ports for the media. (Svrzić, 2019; Mitel Sweden AB, 2017)

MGW information

The command that prints MGW data is: "***media_gateway_info***", and the important parameters are:

• *-attrib* - Feature name,
• *-boo* - Bool value,
• *-mgw-name* - Resource instance,
• *-print* - Read general Media gateway information,
• *-set* - Set data in the resource name,
• *-string* - String value, and
• - Other parameters used to set MGU2. (Svrzić, 2019; Mitel Sweden AB, 2017)

SIP trunking and other features of a modern private automatic telephone network

The IP PINX *MX-ONE Service Node 6.0* is certified for a large number of SIP network providers and complies with the SIP Connect 1.1

standard. The MX-ONE SIP trunking interface is also the basis for integration with "third party" systems, such as Microsoft Linc 2013/Skipe-for-Business, IBM Sametime SUT and other platforms to enable "federation" between different communication platforms (Mitel Sweden AB, 2018a).

The PINX type *MX-ONE Service Node 6.0* can be connected to a private network with other such MX-ONE systems or Mitel's TSW/MD110 systems, as well as with switching systems from other manufacturers. In order to use network services between all participants in such a private network, it must be homogeneous, in terms of the system of applied standardized signaling. This means that trunks to connect telephone exchanges must use the same standardized signaling system, since in the network scenario of switching from one signaling system to another, network services are not supported on the Gateway. Private networks in which trunk connections use ISDN, SIP and H.323 signaling systems are considered homogeneous networks (in terms of signaling). Figure 6 shows the basic scenario of the PINX connection in a modern PISN of a functional user, which can be analogously copied for use in the PATN SAF, provided that the shown IP network Intranet WAN is understood as an existing IP network SAF (Intranet).

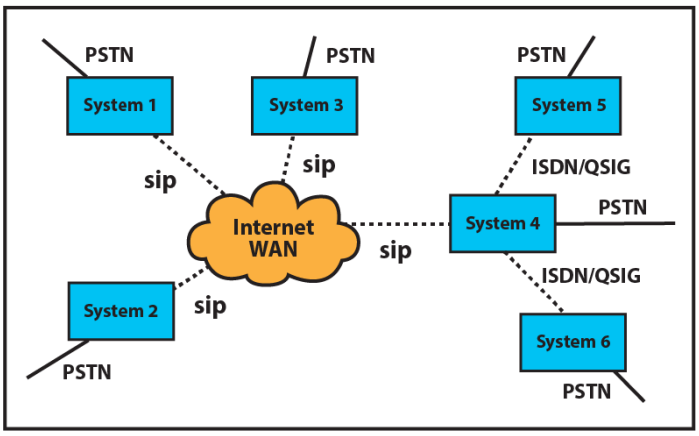


Figure 6 – Principle of the organization of homogeneous PATN with the switching systems Mitel MX-ONE, Mitel TSW/MD110 and those of other manufacturers (Mitel Sweden AB, 2018a)

Рис. 6 – Принцип организации однородного PATN с коммутационными системами Mitel MX-ONE, Mitel TSW/MD110 и системами других производителей (Mitel Sweden AB, 2018a)

Слика 6 – Принцип организације хомогене ПАТлМр са комутационим системима Mitel „MX-ONE", Mitel „TSW / MD110" и других произвођача (Mitel Sweden AB, 2018a)

The figure shows that switching systems 1 to 4, in fact IP PINX of the same manufacturer, are interconnected via the IP network with SIP (and additional proprietary signaling), while switching systems 5 and 6 are ISDN PINX (possibly another manufacturer), connected to the network via transit IP PINX 4 using ISDN Q-SIG (Q-signaling), via transmission systems using TDM. In such an ATN organization, all switching systems shown, i.e. IP PINX and ISDN PINX, can have their own incoming and outgoing external trunks for connection to the PSTN (Public Automatic Switched Telephone Network).

The IP PINX *MX-ONE Service Node 6.0* supports a number of shared user services and ANFs (Additional Network Functions). Typical customer services and network features are: “Call Diversion”, “Call Back”, “Call Intrusion”, “Call Waiting”, and “Bypass Diversion” (overcoming redirects). In order for the mentioned customer services and ANFs to be fully used throughout the entire private automatic telephone network, it is necessary that there exist a "powerful" signaling system in that network, which can transmit all the necessary signaling information. (Svrzić, 2019) (Mitel Sweden AB, 2018a). There are two groups of common network characteristics, i.e. system functions and customer services (which include basic and additional services). System functions are those used to switch and route calls in the network, in a controlled and fast way to the called destinations. The user can only request or influence user services, while he cannot exert any influence on system functions.

In addition to the above, the following interesting features are supported within this type of PINX: "Customer Group", "Hospitality", "VoIP Recording", "Recorded Voice Announcement", "Blasklisting Of Calling Public Subscribers", "Streaming On Idle Extension", some of which could be applicable in the PATN SAF. (Svrzić, 2019; Mitel Sweden AB, 2018a)

Description of the realized software preparation procedures for practical application of Q-SIG tunneling solution on the part of the PATN SAF

The tunneling of Q-signaling through IP proxy using the SIP is practically realized on one part of the PATN SAF, where the interconnection between two participating transit IP PINX type Mitel *MX-ONE Service Node 6.0*, is realized by a transmission beam of 30 IP trunks, and via a connection path organized with a capacity of 10/100 Mb/s Ethernet. The participating end PINXs from the corresponding ISDN

Svrzić, S. et al, Transmission of Q-signaling by the tunneling procedure in the automatic telephone network of integrated services of the Serbian Armed Forces, pp.169-206

parts of the PISN SAF are connected to both transit IP PINX, via the transmission beams of 30 TDM trunks each (with E1/ISDN PRI) and with the application of Network Signaling type Q-SIG. In connection with such a new situation in the PATN SAF, the necessary software interventions (for local resources on the IP PINX itself, and for network resources) were performed on both respective transit IP PINX, necessary to adapt user and network traffic data to the new situation, which was created by introducing a new route and establishing an IP/SIP transmission beam on it. (Svrzić, 2019; Svrzić et al, 2019a)

Numbering plan

The first, and very important, step in defining user data was to supplement the existing Numbering Plan (additional configuration). Therefore, it was very important to determine the parameters for the destination of the newly established route and direct the relevant external destinations from the Numbering Plan to it. The commands that define the numbering plan and read the entered data are: "***number_initiate***" and "***number_end_number_print***".

Common categories

The next step was to define the amendments to the Common Categories, which determine the privileges in the process of making a basic call and user and network services over the newly established route. In this regard, we note that the only some categories of locals have the right of access to external destinations; that the length of dialing digits varies from category to category, etc. In doing so, we distinguish two types of Common Categories: for IP extensions and for analog/digital extensions, which are defined through the CIL interface with different commands. Common categories of IP extensions are defined with the command "***Extension_profile***", while Common categories of analog and digital extensions are defined through the MML commands, with the command "***EXCCS***".

Description of the SIP route definition

To administer specific data about the new route with SIP trunks, the command: "***sip_route***" was used. This specific data is used as a supplement, in addition to the data for defining traditional ISDN routes. Namely, when defining a new SIP trunk, the command "***sip_route***" is used first, and then the so-called "RO" commands: "***ROCAI***", "***RODAI***" and "***ROEQI***". In this case, if necessary, changes in the data to be created with the piece: "***sip_route***", can be made without removing the

"RO" data. Therefore, in the given case, the initialization of the new SIP route took place in 5 steps.

Functioning related to the "sip_route" command

As explained, when the "***sip_route***" command is used, then the new data is used in addition to the traditional "RO" route data. So, the command "***sip_route***" must be used first, then "***ROCAI***", "***RODAI***" and "***ROEQI***". Of course, SIP route data must be present before using the "***ROEQI***" command. Note that the SIP routes can also be configured to only register subscribers in the remote system, without traffic configuration. In the command "***sip_route***", to bind external to internal numbers, together with the command to convert "***number_conversion_initiate***", the commands are used: "***RODDI***: ADC =", "***LCDDI***: BTON =", with parameters "*uristringN*" and "*fromuriN*" (with value N =: 0-7). (Svrzić, 2019; Mitel Sweden AB, 2017)

Appearance of the requested printout to check the set parameters of the initiated SIP route

In order to check the correctness and comprehensiveness of the set parameters of the new SIP route, specific commands are used to print the "RO" and "***sip_route***" parameters. In the practice of the PATN SAF, it could be clearly seen that the default set of parameters, specific to the "***sip_route***" command, is much richer than it was needed for a concrete solution of establishing a new SIP route. Namely, many parameters are irrelevant for a specific case, so they are without set values. (Svrzić, 2019; Svrzić et al, 2019a)

Description of the realized connection of the end ISDN PINX, through tunneling Q-SIG via IP/SIP in the PATN SAF

The scenario for connecting participants from the final ISDN PINX (located on TKC1 and TKC4), realized by applying the Q-SIG tunneling procedure via IP/SIP on the part of the connecting road between transit IP PINX (located on TKC2 and TKC3), in the Private Automatic Telephone Network SAF, is shown in Figure 7 (Svrzić, 2019) (Svrzić et al, 2019a). This situation, which arose on the Core part of the PATN SAF, completely coincides with the situation shown on the standardized PISN model from Figure 4 from the literature: (Ecma International, 2008) and Figure 1 from the literature: (Svrzić et al, 2019a).

In this way, the Q-SIG call initiated by the digital participant "A", connected to the participant board ELU-28 end ISDN PINX, numbering "380-xxx" with TKC1, first uses Q-signaling and voice transmission to the 2 Mbit/s E1 transmission beam according to the transit IP PINX with TKC2, to which the specified ISDN PINX is connected, via the E1 connection on the transmission board TLU-76 and via the transmission system ODS 2.5 Gb/s.

The Q-SIG call initiated by this transmission system comes to the transit IP PINX, as it is brought from its E1 port to the 2 Mb/s E1 interface port of its Media Gateway on the MGU2 board (plays the role of the Inbound Gateway). On the transit IP PINX, the call is processed in cooperation with the Media Server on the ASU-E board, in terms of encapsulating incoming Q-SIG messages (for signaling) and establishing media streams (for speech) within the SIP dialogue (TCP for Q-signaling and UDP for media streams). By applying the Q-SIG and media tunneling process by voice transmission within the SIP, the call over 100 Mb/s IP Switch and 100 Mb/s Ethernet port ODS 2.5 Gb/s crosses over the proprietary IP network with the SIP to the second transit IP PINX with TKC3. With a 100 Mb/s Ethernet port ODS 2.5 Gb/s and via the IP Switch, the call comes to the MGU2 board and the transit IP PINX, i.e. to its Media Gateway (plays the role of the Exit Gateway).

The cooperation between the Media Gateway and the Media Server translates encapsulated Q-SIG messages and UDP media streams from the SIP dialog box into the original Q-SIG processions and the original speech signal in the ISDN format. With a 2Mb / s E1 interface on the MGU2, which is connected to the E1 port of the 2.5 Gb / s ODS transmission system, the Q-SIG call comes to the final ISDN PINX with TKC4. Namely, from the E1 connection of ODS 2.5 Gb / s, the call comes to the transmission board TLU-76, and through local switching ends at the participant "B" connected to the board of digital participants ELU-28, this ultimate ISDN PINX with the numbering "350 -xxx ” which uses Q-SIG on the transmission beam to connect to the transit IP PINX with TKC3. (Svrzić, 2019; Svrzić et al, 2019a)

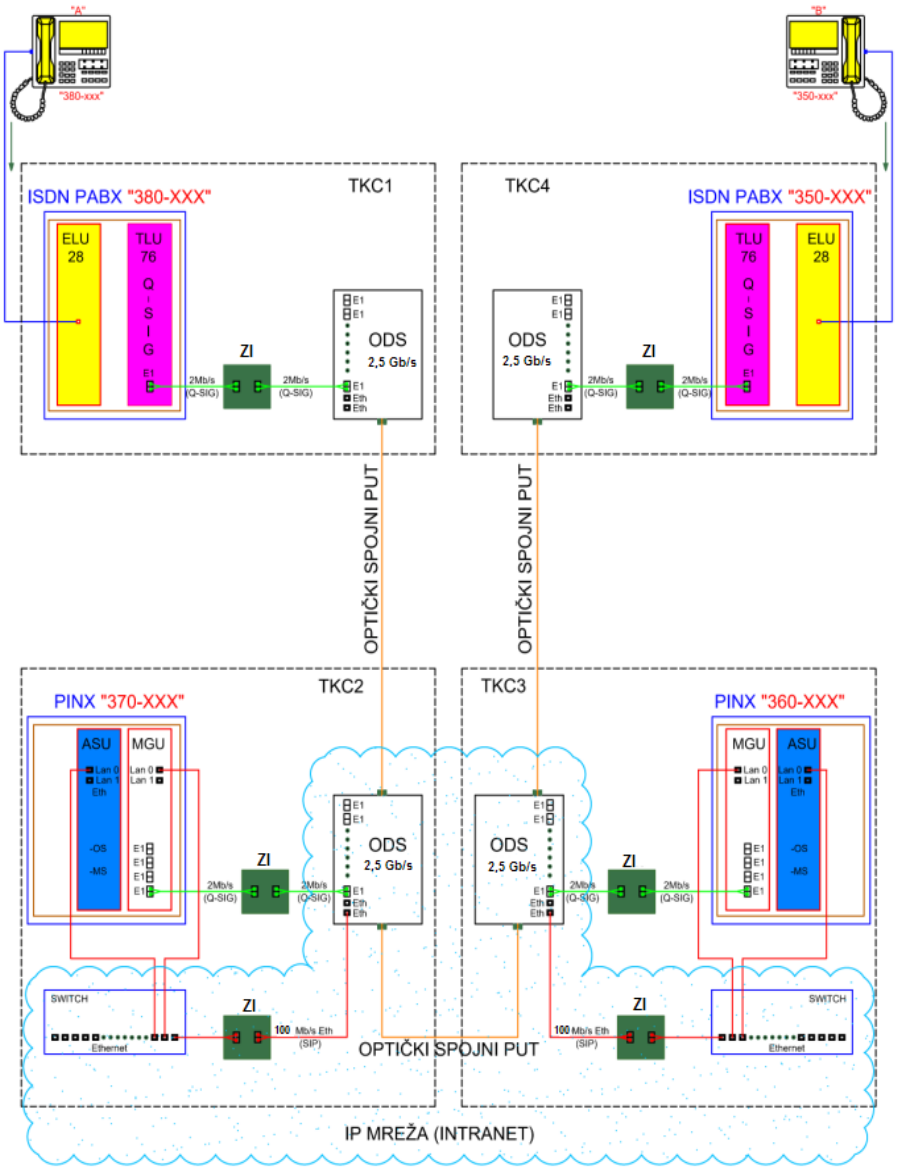


Figure 7 – Scenario of tunneling Q-SIG over the proprietary IP network with the SIP in the PATN SAF (Svrzić, 2019; Svrzić et al, 2019a)
Рис. 7 – Сценарий туннелирования Q-SIG по проприетарной IP-сети с SIP в PATN Вооруженных Силах Республики Сербия (Svrzić, 2019; Svrzić et al, 2019a)
Слика 7 – Сценарио тунеловања Q-SIG преко власничке IP мреже са SIP у ПАТлМр ВС (Svrzić, 2019; Svrzić et al, 2019a)

The realized solution has achieved that, in the PATN SAF, in terms of transmission of basic and additional user services and all network services (as well as special Mitel "proprietary" services), there are no restrictions in terms of either compatibility of Inbound and Outbound Gateways or Q -SIG capabilities and equivalents of the SIP IP network, and there is no loss of parts of Q-SIG in the presented scenario of network "end-to-end" connection. Namely, for Q-SIG tunneling within the SIP, the necessary inter-PINX TCP connection between two Media Gateways from the transit IP PINX with TKC2 and TKC3 is provided via the proprietary IP network. Then the tunnel, provided by the SIP for the transmission of signaling Q-SIG messages via the TCP, acts as a D$_Q$ signaling channel. At the same time, within the SIP established, UDP media streams function as U$_Q$-channels for the transmission of user information (voice, modem information, fax per t.38, data and system messages). (Svrzić, 2019; Svrzić et al, 2019a; Svrzić et al, 2021 – Figure 8).

On the newly established 30-channel SIP transmission beam, the external group protection of information (ZI) was realized regarding tunnel-transmitted signaling criteria from the Q-SIG framework, as well as all user information transmitted through media streams. For this purpose, two types of devices for group crypto protection (GCP) of transmitted information were used:

1) For IP/SIP packet transmission, at the level of 10/100 Mb/s Base-Tx Ethernet which are mounted on both sides of the transmission SIP beam, i.e. of TKC2 and TKC3, and

2) For 2 Mb/s E1 transmission of voice circuits which are mounted on both sides of the transmission ISDN beams, i.e. on TKC1-TKC2 and TKC3-TKC4.

In this way, the necessary continuity of professional information protection was achieved along the entire connection path from the ISDN PINX "380-xxx" with TKC1, through the transit IP PINX "370-xxx" and "360-xxx" with TKC2 and TKC3, to ISDN PINX " 350-xxx ”with TKC4.

The presented transmission network transmission systems (IVN) are IRITEL's Optical Digital Transmission Systems type ODS 2.5 Gb/s, for operation via optical media with applied SDH technology and digital transmission hierarchy. On the participant side, they are configured according to the principle of flexible multiplexers, based on the specific needs of users for capacities of 2 Mb/s E1 and 10/100 Mb/s Base-Tx Ethernet connecting paths, of each of TKC where they are mounted (for connecting telephone exchanges and others functions). As it can be seen

from Figure 7, the capacity of 100 Mbit/s Base-Tx Ethernet ports was used to interconnect the transit IP PINX, with ODS 2.5 Gb/s, while the capacities of E1 ports 2 Mb/s were used to connect the ISDN PINX. (Svrzić, 2019; Svrzić et al, 2019a)

Implementation of the parameters for jitter impact reduction and echo cancellation

During the testing of the implemented solution in the PATN SAF, it was noticed that there were no major problems with the set "RO" and "***sip_route***" parameters, i.e. that

they are professionally set up and that they generally form a realistic backbone for the successful implementation of communications through the network as a whole. The second situation arose with the appearance of jitter on the processions of the RTP packets and echo on the VoIP communication channels, which appeared in the network from the very beginning, so activities had to be taken to reduce the impact of jitter and suppress echoes in order to maintain the quality of audio speech transmission (Svrzić, 2019; Svrzić et al, 2019a; Svrzić et al, 2019b).

There are three basic components on the MGU2 (Media Gateway Unit) boards of the implemented Media Gateways of both transit IP PINX type *MX-ONE Service Node 6.0:*

• TDM Switch, with a switching matrix type T-S-T (Time-Space-Time) 2048 x 64 kb/s,

• Ethernet (Layer 2) LAN, with two 10/100/1000 Base-Tx connections, and

• Media Stream Processor (MSP) for VoIP phone applications and DSP oriented functions, related to the MGU2 (such as VoIP, T.38 and DTMF receivers).

This allows Ethernet signaling packets, such as Non-RTP (say from the TCP), to be routed to the DP (Device Processor) via Switch Layer 2, while Ethernet packets to VoIP, such as the RTP, are routed to the same DP in the Media Steam Processor. (Svrzić, 2019; Mitel Sweden AB, 2017).

On the newly established SIP route between the transit IP PINX (on TKC2 and TKC3), with the TCP protocols for signaling and UDP/RTP for media streams, the network operation was tested in terms of checking the quality of realized VoIP channels, primarily in terms of real presence of jitter on the RTP packets, as well as echoes in speech transmission. The essence was to check, for the first time applied (found), the compromise values of the relevant parameters for reducing the impact of jitter and suppressing the existing echo. Due to the fact that in a given

Svrzić, S. et al, Transmission of Q-signaling by the tunneling procedure in the automatic telephone network of integrated services of the Serbian Armed Forces, pp.169-206

situation, "circuit-switched" calls can sometimes pass through certain VoIP channels (e.g. between two analog phones via two different Gateweys), which then leads to a new delay of about 100 ms, this also had to be taken into account during the testing. (Svrzić, 2019; Svrzić et al, 2019b)

Reducing the impact of jitter

The fact is that the RTP packets, transmitted over the IP network, can realistically have random variations of delay, can arrive out of order, and can be ejected from the procession (in case of excessive delay), which significantly reduces the quality of audio signals. To mitigate this negative impact, a JB (Jitter Buffer) circuit, installed on the MGU2 board, is used. In essence, improving the quality of the audio signal via the JB circuit can only be achieved by applying increased RTP packet delays, which then (when transmitting speech, and especially in combination with the echo at the far end) makes the echo more noticeable and disturbing. "Ad-hock" attempts to minimize this delay in noticeable echo situations can directly affect the degradation of speech quality (e.g. a situation with dropped packets can have a negative impact on the echo transmitter).

In terms of the necessary adaptation of the participating IP PINX to the established jitter in the PATN SAF, the administration of their MGU2 boards was realized with the use of the configuration parameters specially intended for adjusting the JB circuit to real network conditions. The JB circuit can be configured to operate in “adaptive” or “non-adaptive mode”, whereby its configuration is realized on one MGU2 board and affects all VoIP calls in it, including inter-GW media over the IP. (Mitel Sweden AB, 2017). It turned out that the parametric configuration of the JB on the MGU2 of each of the participating IP PINX had to be a compromise between the required audio signal quality and the real increase in delay. By default for "typical networks", the JB in the MGU2 is set to work in the adaptive mode with pre-set, default parameter values in order to preserve the quality of the audio signal in relation to minimizing delays.

However, for those networks that are very sensitive to signal delay, where the desired audio quality must be achieved by adjustment, and/or in the case of a very good network, reconfiguration must be considered, i.e. changing the default values of individual JB circuit parameters, which was also the case in the PATN SAF. Achieved in testing and acceptable in practice, the values of parameters for reducing the impact of jitter on RTP packets in the subject part of the PATN SAF, i.e. in the Core network, through which the prescribed quality of speech through VoIP was achieved, are shown in the table in Figure 8 (Svrzić, 2019; Svrzić et al, 2019b).

	PARAMETAR	VREDNOST	DEFINICIJA I OBJAŠNJENJE
RTP PARAMETRI	***ConfortNoiseGeneration***	_	**Parametar is not used = 0**.
	JB_adaptionPeriod	1000 – 65535 ms	Controls the speed at wtich the jitter buffer can adapt downwards when current network conditions allow. Default is 10 s, which can be set lower for good networks. **Postavili smo vrednost 10.000 ms.**
	JB_delayInit	0 – 200 ms	Initial delay jitter buffer. Default is 0 ms. **Postavili smo vrednost 0 ms.**
	JB_delayMax	0 – 200 ms	Controls maximum size of jitter buffer. Default is 200 ms. If „Hardmode“ is selected this is the maximum size jitter buffer can Grow. If „Softmode“ then deletion occurs at „JB_deletionThreshold“. **Postavili smo vrednost 200 ms.**
	JB_delayMin	0 – 200 ms	Controls minimum size of jitter buffer. Default is 0 ms. **Postavili smo vrednost 0 ms.**
	JB_deletionMode	0 – 1 (boolean)	0 = Softmode (audio quality focus, default). 1 = Hardmode (delay focus). **Postavili smo vrednost 0.**
	JB_deletion Threshold	delay Max 500 ms	Packets exceeding deletion Threshold are deleted. Default is 500 ms. **Postavili smo vrednost od 500 ms.**
	PacketLossThreshold	_	**Parametar is not used = 0**.
	VADTune	.0 - 4	Control VAD threshold to improve bandwidth (low value) or Improve voice quality (high value). Too low value might give Nudesirable impact on voice quality. It is recommended to set at least 1 (default). **Postavili smo vrednost 1.**
	VLANTagValue	0 – 4095	VLAN ID for RTP packets (0 disables VLAN tagging). **Postavili smo vrednost 0.**
Note: *Setting **delayMin** = **delayMax** = **dalayInit** makes jitter buffer non-adaptive.*			

Figure 8 – Set parameters and their values to reduce the impact of jitter on RTP packets (Svrzić, 2019; Svrzić et al, 2019b)
Рис. 8 – Установленные параметры и их значения для снижения влияния джиттера на пакеты RTP (Svrzić, 2019; Svrzić et al, 2019b)
Слика 8 – Постављени параметари и њихове вредности за смањење утицаја џитера на RTP пакетима (Svrzić, 2019; Svrzić et al, 2019b)

During the testing, some experiences related to the "fight" against jitter were gained. Namely, the JB circuit is primarily intended for the adaptation of the MGU2 to the negative effects caused by the IP network itself, but it should always be borne in mind that VoIP endpoints (IP phones, gateways, IP proxies, etc.) are also parts of the network that can cause such influences.

Svrzić, S. et al, Transmission of Q-signaling by the tunneling procedure in the automatic telephone network of integrated services of the Serbian Armed Forces, pp.169-206

Soft SIP clients without a dedicated HW timeslot number (e.g. Digital Signal Processor) in VoIP media will have significantly more jitter in outgoing RTP packets than it is the case with HW (Mitel Sweden AB, 2017). This can then cause an increase in the time buffer in the JB, thus further increasing the total delay present. Therefore, in these and similar network scenarios, the delay over the MGU2 may be longer than expected, which should certainly be taken into account in further practice. (Svrzić, 2019; Svrzić et al, 2019b)

Echo suppression

The EC (Echo Canceler) is an integrated circuit on the MGU2 board designed to suppress the echo for calls over the IP-IP network with packet switching (VoIP). On the part of the circuit-switched network, echo is created when a part of the packet network transmitting signal is mapped to the return signal, i.e. the packet network receiving signal.

Echo is usually caused by reflections at the transitions from 2-wire to 4-wire transmission media (on the part of the circuit-switched network), but there is also acoustic echo in telephones. This then means that, in a real network, the EC setting must also be performed as a compromise. Namely, in VoIP calls, the occurrence of echo, in combination with delays caused by the IP network, is more disturbing than the echo in the TDM network with circuit switching, in which it may happen that there is no signal delay at all. In fact, on the packet-switched network side, the user perceives echo as the sum of echoes: from the source + from the suppression operation + from the packet network delays (includes: delays in Media Gateways during encoding/decoding and in the JB); delay in the transport part of the network during switching and in routers; delay at endpoints when encoding/decoding and in the JB). (Mitel Sweden AB, 2017; Svrzić, 2019; Svrzić et al, 2019b)

The MGU2 board, implemented in the IP PINX PATN SAF, supports two types of EC for VoIP Gateway calls: Standard EC and Dual Filter EC (DFEC). Care should be taken when choosing the type of echo suppressors and their settings, because in addition to affecting all VoIP calls established via this MGU2 board (including inter-GW media over the IP), they also have a large impact on the load of the MSP (Media Steam Processor). Of course, changing the EC type will immediately trigger a restart of the MCA (Media Control Application) as well as the MSP. The EC circuit also includes a NLP (Non-Linear Processor), i.e. a sub-function that is able to "handle" the nonlinear part of the residual echo, and which the linear EC filter from the circuit cannot cancel. By default, the NLP is "disabled" during setup and is recommended to be "enabled"

only when necessary. When the NLP is "enabled" and switched on, it generates CN (Comfort Noise) to the IP network. However, if for any reason it is not desirable, CN Generating can also be discontinued to produce silence (Mitel Sweden AB, 2017).

With the selected "Standard EC", the length of the "Echo tail" can be adjusted from 8 to 128 ms, in steps of 8 ms, while the filter window is fixed at 24 ms. The advantage of "Sparse EC" is MIPS savings that correspond to higher channel density. "Standard EC" can be improved by "enabling EPCD (Echo Path Change Detection)", which then improves the adaptation of the filter window position. Setting up the EPCD will cause the MCA (Media Control Application) to be restarted (Mitel Sweden AB, 2017).

With the selected "DFEC (Dual-Filter EC)" the length of the "Echo tail" can also be set from 8 to 128 ms, in steps of 8 ms, with the advantages of its application: avoidance of increased echo levels caused by filter divergence during bidirectional conversations and robust and fast detection of echo path changes. The main disadvantage is that DFEC reduces the density of DSP channels. (Mitel Sweden AB, 2017).

During the testing, all the mentioned conditions were taken into account, so through several iterations, a configuration of parameters acceptable for practice was reached and their values are shown in the table in Figure 9 (Svrzić, 2019; Svrzić et al, 2019b).

The experience gained shows that the following practical procedures are recommended for suppressing disturbing echo network VoIP traffic in the PATN SAF:

1. The EC must be switched on thus enabling the Echo suppression function. The path of the media on which the transition from the IP to the TDM takes place (in the Media Gateway where calls are routed to/from the public ISDN trunk) is interesting. The “ClearChannel” parameter (i.e. ClearMode) must not be enabled, as this type of codec is not used for RTP. The RTP mode requires that the EC is always on.

2. The NLP (Non Linear EC Processor) function must be enabled, as it eliminates nonlinear residual echo which cannot be solved by a linear plate filter.

3. The "Dual-Filter EC" algorithm must be included, as it significantly improves echo suppression, but with caution, as DFE may have some negative impact on the capacity of the MGU2.

4. If, after (re) configuration, echo reappears, you should check whether the new parameter configuration is fixed. For example: whether the parameters for "reload" are marked in the PINX itself, and whether a "back-up" of data has been made.

Svrzić, S. et al, Transmission of Q-signaling by the tunneling procedure in the automatic telephone network of integrated services of the Serbian Armed Forces, pp.169-206

Name	Value range	Description	EC type
EC_ECType	0..1	***Select Echo Canceller type*** ***0=Standard Echo Canceller (STD)*** 1=Dual-Filter Echo Canceller (DFE)	***STD***
EC_DFECFilterSize	8..128ms (in step of 8 ms)	***Filter length for DFEC=64ms***	***DFE***
EC_DFECMinErl		***DFEC Minimum ERL setting (do not change) =20675***	***DFE***
EC_DFECAttenuattion		***DFEC Rx output digital gain (do not change) =0***	***DFE***
EC_ECCrossCorrelationCalculation		***Not used***	-
EC_EchoPathChange	„false“/“true“	***„false“=Disable EPCD*** “true“=Enable EPCD	***STD***
EC_ErlChangeDetection		***Not used***	-
EC_FastConvergenceControl	„false“/“true“	***Accelerates filter convergence for long filters=„false“***	***STD***
EC_ECWindowsSize	24 ms	***EC windows size for standard EC=24ms***	***STD***
EC_NLPControl	„false“/“true“	***„false“=Disable EPCD*** “true“=Enable EPCD	***STD***
EC_ELPTune	0..2	***Not used***	***STD***
EC_ECTailLenght	8..128ms (in step of 8 ms)	***Filter length for STD EC=64ms***	***STD***
EC_EchoCancellerEnable		***Not used***	-
EC_CNGEnable	„false“/“true“	***CNGEnable =”true”***	***STD***
SilenceToPCMInterface	„false“/“true“	***Not used (parameter is controlled indirectly by CNG settings) =”true”***	-

Note: *The column tells for which EC type the parameter is valid.*
Note: *Changing EC parameters for default values might lower VoIP channel and other DSP resource densities.*

Figure 9 – Adjusted parameters for echo cancellation on VoIP channels (TDO MO) (Svrzić, 2019; Svrzić et al, 2019b)
Рис. 9 – Скорректированные параметры для эхоподавления на каналах VoIP (TDO MO) (Svrzić, 2019; Svrzić et al, 2019b)
Слика 9 – Подешени параметри за потискивање еха на VoIP каналима (TDO MO) (Svrzić, 2019; Svrzić et al, 2019b)

5. When, in practice, the echo duration is longer than the default value of 64 ms, the set EC cannot cancel it, so the default EC setting must be changed and adjusted to the actual echo duration. The duration of echo is the time that elapses from the moment when the speaker (medium) from the IP side sends a signal to the TDM side of the network to the moment when a part of that signal is returned (from the TDM network) to the speaker on the IP side (of course, attenuated). Changes to this parameter are made in steps of 8 ms, up to a maximum value of 128 ms.

6. If the duration is 64 ms <Echo <128 ms, then the appropriate length of the filter window can be set in the EC. Since the usual echo length is less than 10 ms, the length of the filter window should be set to 24 ms. However, in exceptional situations, the duration of echo can be much longer, so this should be taken into account. Inadequately set duration of the filter window can have a certain negative impact on the capacity of the MGU2. (Svrzić, 2019; Svrzić et al, 2019b)

Conclusion

In the PATN SAF, the applied tunneling procedure for the transmission of encapsulated messages from Q-SIG, defined by the global ECMA-355 Standard, enabled calling between PINX, i.e. "islands" within PISN parts with circuit-switched circuits that use Q-signaling, although they are interconnected, in one part, by the transport IP network (which uses the SIP). At the same time, without any loss of Q-SIG functionality, the connection of participants with the specified end PINX is realized, by transiting through the IP PINX type Mitel *MX-ONE Service Node 6.0,* which are interconnected by Core network. This then concretely means that through the heterogeneous

Telecommunication-information Network of the Serbian Armed Forces, according to the type of connection "from end to end", all basic and additional participation services and network functions of the ISDN are successfully transmitted.

The realized solution, through the Intranet SAF, logically connected the mentioned transit IP PINX, i.e. helped establishing their mutual communication known as an Inter-PINX link, which contains a signal channel, known as a D**Q**-channel, and one or more channels for user information, known as U**Q** channels. Through the IPL, Mitel's IP PINX *MX-ONE Service Node 6.0* successfully realizes one required TCP connection to support the D**Q**-channel and one pair of UDP media streams to support the U**Q**-channels, thanks to the use of mapping functions that take place in accordance with the global ECMA-336

Standard. Within the TCP connection, these IP PINXs transmit the encapsulated Q-SIG messages and Resource Control Information, which are necessary for the establishment of UDP streams, together on the DQ channel.

The applied solution for tunneling Q-signaling via the transit IP PINX, through the organization of the SIP transmission beam through its own IP network (Intranet SAF) on the Core part of the Automatic Telephone Network SAF, represents a novelty in the organization and operation of the PTN SAF. In this way, the service life of the Q-SIG type network signaling system, proven in practice, has been extended in the PATN SAF. By tunneling Q-SIG and transmitting without degradation through the mentioned IP network with the SIP (encapsulation of Q-SIG messages into SIP dialogue messages), it was achieved that the PATN SAF does not violate the previously built PISN status, also in parts where its TDM/ISDN parts connect to IP Proxy. In addition, monitoring the operation in the network helped in gaining necessary experience related to quality software preparation and to defining traffic parameters of the SIP route as well as to the application of the necessary procedures to reduce the impact of jitter and suppress echoes, with a view to raising the quality of VoIP communications in the network. Equally important is the practical knowledge acquired during the physical realization of completing, connecting, adapting and adjusting the necessary participating hardware equipment (for switching, IP transmission, IP Switching, group cryptosecurity on IP and TDM trunks) and using its elements and details, which will, together with the knowledge acquired in the preparation of software and the selection of the traffic parameters of the SIP route, as well as in "fights" with jitter and echo, be applied to some of future TKC SAF, following the growth rate of the Core network.

In addition to the above, in the PATN SAF, the new solution with the use of the IP network to connect the IP PINX using the Q-SIG tunneling procedures opens a whole range of other modern possibilities that will, with the undoubted growth of the Core network, contribute to the creation of a wide territorial platform and the implementation of multi-timed communications in real time, thus leading to the transition to UC (Unifed Communications).

References

Baugher, M., McGrew, D., Naslund, M., Carrara, E. & Norrman, K. 2004. RFC-3711: The Secure Real-time Transport Protocol (SRTP). In: *IETF - Internet Engineering Task Force* [online]. Available at: https://tools.ietf.org/html/rfc3711 [Accessed: 16 February 2021].

Deering, S. & Hinden, R. 1998. RFC 2460 - Internet Protocol, Version 6 (IPv6) Specification. In: *IETF - Internet Engineering Task Force* [online]. Available at: https://tools.ietf.org/html/rfc2460 [Accessed: 16 February 2021].

Dierks, T. & Rescorla, E. 2006. RFC-4346: The Transport Layared Security (TLS), Version 1.1. In: *IETF - Internet Engineering Task Force* [online]. Available at: https://tools.ietf.org/html/rfc4346 [Accessed: 16 February 2021].

Dierks, T. & Rescorla, E. 2008. RFC-5246: The Transport Layared Security (TLS), Version 1.2. In: *IETF - Internet Engineering Task Force* [online]. Available at: https://tools.ietf.org/html/rfc5246 [Accessed: 16 February 2021].

-Ecma International. 2002. *Standard ECMA-336: Private Integrated Services Network (PISN) - Mapping Functions for the Tunnelling of QSIG through IP Networks (Mapping/IP-QSIG)* [online]. Available at: https://www.ecma-international.org/publications/standards/Ecma-336.htm [Accessed: 16 February 2021].

-Ecma International. 2008. *Standard ECMA-355: Corporate Telecommunication Networks - Tunnelling of QSIG over SIP* [online]. Available at: https://www.ecma-international.org/publications/standards/Ecma-355.htm [Accessed: 16 February 2021].

-InterConnect Communication Ltd. 1995. *QSIG. The Handbook for Communications Managers*. Gwent, U.K: InterConnect Communications Ltd. ISBN: 1870935098.

-Mitel Sweden AB. 2017. *MiVoice MX-ONE Media Gateway Unit MGU2 Description. 21/1551-ANF 901 36 Uen D.* Stockholm, Johanneshov, Sweden: Mitel Sweden AB.

-Mitel Sweden AB. 2018a. *MiVoice MX-ONE System Description. 21/1551-ASP 113 01 Uen AA.* Stockholm, Johanneshov, Sweden: Mitel Sweden AB.

-Mitel Sweden AB. 2018b. *MiVoice MX-ONE Media Server Description. 70/1551-ANF 901 14 Uen F.* Stockholm, Johanneshov, Sweden: Mitel Sweden AB.

Svrzić, S. 2019. *Analiza mogućnosti i primene Q signalizacije u heterogenoj telefonskoj mreži funkcionalnog korisnika*. MSc thesis. Belgrade: University of Belgrade - School of Electrical Engineering (in Serbian).

Svrzić, S., Čiča, Z., Miličević, Z. & Perišić, Z. 2019a. Q-SIG over SIP tunneling in PISN with integrated services of functional user (in Serbian). In: *Proceedings of 6th IcETRAN - International Conference on Electrical, Electronic and Computing Engineering*, Silver Lake, Serbia, pp.1009-1014, June 3-6 [online]. Available at: https://etran.rs/2019/Proceedings_IcETRAN_ETRAN_2019.pdf [Accessed: 16 February 2021].

Svrzić, S.M., Čiča, Z.M., Miličević, Z.M. & Perišić, Z.S. 2019b. Echo Cancellation and Jitter Reduction in Q-SIG Tunneling over SIP in the Private Integrated Services Network (in Serbian). In: *Proceedings of TELSIKS - 14th International Conference on Advanced Technologies, Systems and Services in Telecommunications*, Niš, Serbia, pp.286-289, October 23-25.

Svrzić, S. & Jovanovski, P. 2021a. Description of the TETRA1 technology and standard for modern digital tranking systems of functional mobile radio communictions. *Vojnotehnički glasnik/Military Technical Courier*, 69(3), pp.687-726. Available at: https://doi.org/10.5937/vojtehg69-30858.

Svrzić, S.M., Miličević, Z.M. & Perišić, Z.S. 2021b. Description of the process of tunneling Q signaling in private telecommunications networks. *Vojnotehnički glasnik/Military Technical Courier*, 69(1), pp.31-63. Available at: https://doi.org/10.5937/vojtehg69-28117.

ПЕРЕДАЧА Q-СИГНАЛИЗАЦИИ МЕТОДОМ ТУННЕЛИРОВАНИЯ В АВТОМАТИЧЕСКОЙ ТЕЛЕФОННОЙ СЕТИ ИНТЕГРИРОВАННЫХ СЛУЖБ ВООРУЖЕННЫХ СИЛ РЕСПУБЛИКИ СЕРБИЯ

Сладжан М. Сврзич[а], *Юлиян* К. Боянов[б]

[а] ООО “Тесла системи“, г. Белград, Республика Сербия, **корреспондент**
[б] «SoftServe», г. София, Республика Болгария

РУБРИКА ГРНТИ: 49.00.00 СВЯЗЬ:
49.33.00 Сети и узлы связи;
49.33.29 Сети связи
ВИД СТАТЬИ: обзорная статья

Резюме:

Введение/цель: Цель данной статьи заключается в упорядочении практического применения Стандартов ECMA-355 и ECMA-336 туннелирования Q-SIG и реализации функций мапирования через существующую сеть IP (Интернет-протокол) Вооруженных сил Республики Сербия (Интранет SAF) в Частной автоматической телефонной сети SAF (PATN SAF), которая является основной частью Частной телекоммуникационно-информационной сети интегрированных услуг ВС (PISN SAF).

Методы: Описание внедренного решения и анализ программных параметров установленного маршрута передачи SIP, с представлением результатов, полученных в процессе предотвращения джиттера и эхопадавления в сети.

Результаты: С помощью данного решения участникам из периферийных частей PISN SAF, которые работают по принципу передачи и коммутации каналов с помощью TDM (Мультиплексирование с временным разделением), обеспечена связь друг с другом через новосозданную центральную IP-сеть SAF (Опорная сеть), которая работает по принципу передачи и коммутации пакетов с SIP (Протокол установления сеанса), без потери функциональности Q-SIG в рамках цифровой телекоммуникационной сети интегрированных услуг ISDN (Интегрированные услуги цифровой сети).

Выводы: В статье рассматриваются особенности современной сети IP PINX (Частная сеть с интеграцией услуг) производства Mitel, тип MX-ONE Service Node 6.0, которая внедрена на транзитном уровне PATN SAF и успешно осуществляет процесс туннелирования Q-SIG через IP-сеть и необходимые функции для мапирования передачи туннелированных сообщений Q-SIG и мапирования голосовой (и другой аудио) информации в медиапотоки VoIP (Передача голоса по IP) по данной сети. Также приведены основные элементы для ее программной подготовки во время внедрения нового маршрута SIP с пропускной способностью 30 IP-магистралей в луче передачи, реализованном со скоростью Интернета 100 Мб/с-Т, и описаны методы эхоподавления и устранения джиттера. В заключении статьи представлены экспериментально полученные значения параметров для уменьшения влияния джиттера и эхоподавления.

Ключевые слова: PATN SAF, Q-SIG, PISN, IP PINX, MX-ONE, медиасервер, туннелирование Q-SIG, инкапсуляция, функции мапирования, джиттер, эхо.

ПРЕНОС Q-СИГНАЛИЗАЦИЈЕ ПОСТУПКОМ ТУНЕЛОВАЊА У АУТОМАТСКОЈ ТЕЛЕФОНСКОЈ МРЕЖИ ИНТЕГРИСАНИХ СЕРВИСА ВОЈСКЕ СРБИЈЕ

Слађан М. Сврзић[а], *Јулијан* К. Бојанов[б]

[а] Тесла системи д.о.о., Београд, Република Србија, **аутор за преписку**
[б] „SoftServe", Софија, Република Бугарска

ОБЛАСТ: телекомуникације
ВРСТА ЧЛАНКА: прегледни рад

Сажетак:

Увод/циљ: Циљ овог рада је да се специфицира практична примена Стандарда ECMA-355 и ECMA-336 за тунеловање Q-SIG и реализацију функција мапирања, преко постојеће IP (Internet Protocol) мреже Војске Србије (Интранет ВС), у приватној аутоматској телефонској мрежи ВС (ПАТлМр ВС), која чини главни део приватне телекомуникационо-информационе мреже интегрисаних услуга ВС (ПИСН ВС).

Методе: Описано је имплементирано решење и анализирани софтверски параметри успостављене преносничке SIP руте, са приказом резултата добијених у борби са џитером (Jitter) и ехом (Echo) у мрежи.

Резултати: Приказаним решењем постигнуто је да учесници са рубних делова ПИСН ВС, који функционишу на принципу преноса

Svrzić, S. et al, Transmission of Q-signaling by the tunneling procedure in the automatic telephone network of integrated services of the Serbian Armed Forces, pp.169-206

и комутације кола по TDM (Time Division Multiplexing), могу међусобно остварити везу и преко новоуспостављене централне IP мреже ВС (Core мрежа), која функционише на принципу преноса и комутације пакета са SIP (Session Initiation Protocol), а без губитка функционалности Q-SIG из оквира дигиталне телекомуникационе мреже интегрисаних сервиса ISDN (Integrated Services Digital Network).

Закључак: Анализирана је савремена IP PINX (Private Integrated Services Network Exchange) произвођача Mitel, типа „MX-ONE Service Node 6.0", која је имплементирана на транзитном нивоу ПАТлМр ВС. Она успешно реализује како поступак тунеловања Q-SIG кроз IP мрежу, тако и неопходне функције за мапирање преноса тунелованих порука Q-SIG и мапирање говорних (и других аудио) информација на медија токове VoIP (Voice over IP) комуникације кроз ту мрежу. Такође, наводе се основни елементи за њену софтверску припрему при увођењу нове SIP руте, капацитета 30 IP транкова у преносничком снопу реализованом 100 Mb/s-T Ethernet-ом, те описује борба са присутним Jitter-ом и Echo-ом у мрежи. На крају се презентују и искуствено постигнуте вредности параметара за смањење утицаја џитера и потискивање еха.

Кључне речи: ПАТлМр ВС, Q-SIG, PISN, IP PINX, MX-ONE, медија гејтвеј, медија сервер, тунеловање Q-SIG, енкапсулација, мапирање функција, џитер, ехо.

Paper received on / Дата получения работы / Датум пријема чланка: 19.07.2021.
Manuscript corrections submitted on / Дата получения исправленной версии работы / Датум достављања исправки рукописа: 03.01.2022.
Paper accepted for publishing on / Дата окончательного согласования работы / Датум коначног прихватања чланка за објављивање: 04.01.2022.

Основни борбени тенк Т-80BVM улази у оперативну употребу на Арктику[1]

Руски тенк Т-72B3M на проби пред параду за Дан победе 2017. године Виде се кутије реактивног оклопа 4S24 око куполе, као и додатне заштитне завесице са стране тенка.

Тенк Т-80BVM развила је компанија „Omsktransmash" као модернизацију руских тенкова Т-80В и Т-80BV који представљају најмодерније верзије серије Т-80.

Тенкови Т-80 налазили су се, од времена хладног рата, у неколико руских оклопних јединица , а нови корисници модернизоване верзије Т-80BVM биће осамдесета и двестота моторизована бригада које се налазе у области Мурманск, а деловаће у арктичком региону.

Уговор за модернизацију 62 тенка који ће битимодернизовани на стандард Т-80BVM потписан је 2017. године. Очекује се да ће бити потребно 124 тенка за опремање две моторизоване бригаде.

[1] Janes international july 2020

Vučković, D., SAVREMENO NAORUŽANJE I VOJNA OPREMA / MODERN WEAPONS AND MILITARY EQUIPMENT, pp.207-216

Модернизована верзија тенка Т-80, без бочних заштитних завесица, испоручена је новим моторизованим бригадама.

Тенк Т-80 предвиђен је за оперативну употребу на Арктику првенствено због своје гасне турбине. Наиме, у екстремно хладним условима гасна турбина тенка Т-80BVM стартује за 52 секунде, док је обичном дизел мотору потребно чак 45 минута.

До сада су виђене три верзије стандарда Т-80BVM. Прва верзија приказана је у Луги током Дана тенкиста 2017. године, као и на вежбама „Запад 2017". Од осталих верзија разликује се по експлозивно-реактивном оклопу, са касетама 2S42 Relikt на бочним странама куполе. Ова верзија носи назив Т-80BVM (2017).

Друга верзија приказана је у Владивостоку током припрема за параду поводом Дана победе, маја 2018. године.Претпоставља се да је намењена морнаричкој пешадији. Ова верзија нема бочне заштитне завесице већ је опремљена са три мање заштитне плоче на бочним странама тенка, ближе предњем делу. Његова званична ознака није Т-80BVM већ Т-80BV(2018), јер је модернизован неким новим подсистемимаи знатно је јефтинији од верзије Т-80BVM. Коначна верзија има ознаку Т-80BVM (2019) и приказна је октобра 2019. године. Овај тенк могуће је препознати по изостанку блокова експлозивнореактивног оклопа са стране купола.

Претпоставља се да су верзије 2018 и 2019 ушле у оперативну употребу, док верзија 2017 није. Разлог је, можда, скупа додатна заштита куполе која није исплатива за серијску производњу.

Процењене способности

Тенк Т-80BVM (2019) значајно је унапређен у односу на серије Т-80B/BV. Маса тенка је повећана са 43,7 тона колико је био тежак модел Т-80BV на 46 тона. Повећање масе тенка захтевало је и повећање снаге мотора GTD-1000TF, 1100 КС која се налази на моделу Т-80B/BV.

Бочне завесице на тенку 72B3M.

Тенк Т-80BVM је опремљен новим мотором GTD-1250TF који развија снагу до 1250 КС. Нови мотор обезбеђује и мању потрошњу горива у односу на GTD-1000TF, нарочито када мотор ради на леру. Повећана ефикасност мотора омогућава максималан радијус дејства до 500 км, што је знатно више од 335 км коју постиже верзија Т-80B/BV. Моћнији мотор омогућава тенку Т-80BVM и бољи однос од 27,17 КС/Т у односу на 25,17 КС/Т претходне верзије.

Максимална брзина није потврђена, али је руско министарство одбране навело да је максимална брзина тенка 70 км/ч. Телевизијски канал „Звезда" приказало је снимак тенка који достиже брзину од 77 км/ч на стази прекривеној снегом, што наводи на закључак да би брзина на путу могла бити још већа.

По питању заштите, тенк Т-80BVM је опремљен пакетом активно експлозивно-реактивног оклопа Relikt који је заменио оклоп типа Kontakt-1 са тенка Т-80BV. Нису доступне прецизне карактеристике оклопа типа 4S23 Relikt, али се претпоставља да је намењен заштити против тандем високоекплозивне бојеве главе, која може да пробије до 1.000 мм ваљаног

Vučković, D., SAVREMENO NAORUŽANJE I VOJNA OPREMA / MODERN WEAPONS AND MILITARY EQUIPMENT, pp.207-216

хомогеног оклопа, као и заштити против поткалибарних пројектила (APFSDS) намењених пробоју до 800 мм ваљаног хомогеног оклопа.

Уколико би се ови подаци другачије приказали, Relikt умањује пенетрацију кумулативне/високоексплозивне бојеве главе до 90% и до 50% пробојност покалибарног прјектила типа APFSDS. Експлозивно-реактивни оклоп (EPO) Relikt распоређен је око и изнад куполе, а на бочној страни возила налазе се заштитне завесице у којима су џепови са плочама EPO типа 4S24.

Сматра се да при употреби бочних џепова са EPO ниво заштите расте двоструко с обзиром на то да надолазећи пројектили морају пробити два слоја EPO. Задње стране шасије и куполе могу бити опремљене решеткастим оклопом ради заштите од ручних бацача типа PG-7V или сличних оружја.

Тенк T-80BVM је опремљен и радио-уређајем R-168-25Y-2 VHF и интерним комуникационим системом. Радио-систем припада садашњој генерацији из породице R-168 Akveduk уместо из породице R-187 Azart који су софтверски дефинисани. Русија је одлучила да користи старији радио-систем у тенку T-80BVM, вероватно ради умањења трошкова, али постепено уводи радио-системе из породице R-187 Azart због бољег умрежења и отпорности на ометање.

Тенк T-80BVM опремљен је топом 125 мм 2A46M-4 који представља модернизован топ 2A46M-1 истог калибра који се користио на старијим серијама T-80. Из компаније „Uralvagonzavod" (UVZ) објашњавају да се унапређења новог топа односе на повећану чврстину и прецизност. Произвођач тврди да је дошло до повећања прецизности за 20%, као и повећања прецизности током испаљења у покрету за 1,7 пута у односу на топ 2A46M-1. Међутим, по расположивим снимцима види се да топ није опремљен референтним системом на устима цеви који једео новог топа 2A46M-4. Могуће је да је тај систем скинут са топа ради уштеде или да ће бити накнадно инсталиран.

Топ је упарен са новим нишанским уређајем Sosna-U који поседује дневне и термалне канале, а користе га нишанџија и командир. Овај нишански уређај може открити мету величине тенка на даљини до 5.500 м дању и 3.000 м у ноћним условима и има могућност аутоматског праћења циља. Нишански уређај повезан је са дигиталним системом за контролу ватре који има метеоролошки сензор, балистички компјутер и унапређени стабилизатор 2E58. Нишанџија може да користи и допунску нишанску справу 1G46-2 која се налази на неким унапређеним тенковима T-80U .

Снимци показују да командир располаже унапређеном панорамском ноћном и дневном осматрачком справом TKN-3MK која се налази на тенковима T-72B3. Међутим, овај осматрачки уређај не може идентификовати циљеве ноћу на даљинама преко 500 м, па је потребно користити нишанску справу Sosna-U за проналажење мета на средњим даљинама током ноћи. Возач користи дневно-ноћну осматрачку справу која се налазила на неким ранијим серијама тенкова T-80, а која обезбеђује

увећање од једног пута на слици од 27 степени хоризонталне и 36 степени вертикалне видљивости.

Тенк је опремљен и системом 9K119M Refleks-M, што омогућава возилу лансирање противтенковске вођене ракете 9M119M1 Invar-M са тандем бојевом главом из топа. Ракета може пробити 900 мм ваљаног хомогеног челика иза ERO,

Ватрена моћ

Најзначајније унапређење на пољу ватрене моћи представља модификација аутоматског пуњача којом је омогућено пуњење дуже поткалибарне муниције (APFSDS). Када се ради о балистици и пробојности потребно је узети више фактора у обзир, као што су брзина пројектила на устима цеви, тип пуњења, аеродинамика, однос дужине и дијаметра, тежина и састав зрна, дизајн пенетратора и подаци о интеракцији пенетратора и материјала циља. Поред тога, дужи пенетратори типа APFSDS обично пробијају дуже кроз оклоп циља у односу на краће пенетраторе уколико оба имају исте брзине на устима цеви.

Пројектил 3BM42 Mango на доњем делу слике и експериментални пројектил Mango-M на горњем делу слике.

На старијим руским тенковима Т-72, Т-80 и Т-90 максимална дужина пенетратора била је ограничена аутоматским пуњачем и износила је око 640 мм. На основу тога, најдужи прихваћени пенетратор био је 3ВМ42 Mango дужине од 574 мм који је могао да пробије од 500 до 520 мм вертикалног ваљаног хомогеног челика, што је падало на 220 до 230 мм вертикалног ваљаног хомогеног челика под нагибом од 60 степени. Пројектил 3ВМ42 Mango био је у оперативној употреби од 1986. године, али му је пробојност знатно опала у односу на развој савременог оклопа.

Русија је, почетком деведесетих година, уложила труд да уведе пенетраторе у облику пројектила 3ВМ46 Svinets чија је дужина од 640 мм, а одскора и више, са новим извозно оријентисаним пројектилом 3ВМ42М Mango-M дужине од 610 мм који би био компатибилан са старијим аутоматским пуњачима из постсовјетског доба. Међутим, и овакав пројекат је заостајао за пројектилима модерних НАТО тенкова који користе знатно дуже пенетраторе, као што су амерички М829А1 дужине од 684 мм или немачки DM 53 дужине од чак 745 мм.

Главну препреку развоју дужих пенетратора представља сама димензија аутоматских пуњача коју користе руски тенкови. Због тога је приоритет свих новијих модификација руских тенкова, укључујући Т-72В3, Т-72В3М, Т-80ВВМ и Т-90М, постао поновно пројектовање аутоматских пуњача који би примали муницију дужу од 740 мм.

Новија поткалибарна муниција (APFSDS) коју могу користити ови тенкови је типа 3ВМ59 Svinets-1 и 3ВМ60 Svinets-2 дужине од 735 мм. Руски извори су навели да пројектил Svinets-1 има пенетратор од волфрамовог карбида чија је пробојност од 700 до 740 мм ваљаног хомогеног челика, док пројектил Svinets-2 користи пенетратор од осиромашеног уранијума пробојности од 800 до 830 мм ваљаног хомогеног челика, с тим да се ове вредности односе на вертикално постављену челичну плочу, на даљини од 2 км. Међутим, ови подаци нису потврђени.

На изложби наоружања Armiya-2019, компанија „Текмаш" приказала је пробојност 600 мм ваљаног хомогеног челика на непознатој даљини пројектилом Svinets-2. Међутим, потпуна пробојност није откривена. У сваком случају, нови пројектили ипак представљају значајно унапређење ватрене моћи руских тенкова.

Ипак, Svinets-1 и Svinets-2 се не могу поредити са пројектилима Vacuum-1 (Волфрам) и Vacuum-2 (осиромашени уранијум) који су развијени за тенк Т-14 Armata чији пенетратори имају дужину од 900 мм. Увођење овако дугих пенетратора није било могуће са старим аутоматским пуњачима и захтевало је дужи труп и већи аутоматски пуњач, као и топ са већим притиском 2А82-1М.

Други корисници совјетских тенкова, као што су Пољска и Украјина, такође су покушали да превазиђу проблем ограничења аутоматског пуњача. Пољско решење слично је руском и састојало се у поновном пројектовању аутоматског пуњача ради прихватања дужих пројектила. Пројектован је прототип пуњача Bumar-Łabędy за тенк PT-91M2, али није

познато да ли је Пољска прихватила ово решење за модернизацију свог тенка T-72 mod.2019. Украјина је прибегла можда и ектремнијем приступу за свој прототип T-84-120 Yatagan, што је укључивало увођење топа у НАТО калибру од 120 мм и једноделно зрно, а тиме и избацивање постојећег аутоматског пуњача и додавање новог. Ова верзија тенка намењена је извозу, али није познато да ли је било поруџбина до сада.

Рад на модернизацији тенка T-80BVM одвија се у фабрици „Omsktransmash" у Омску, док се поправке и тестирања тенкова серије T-80 обављају у шездесет првом постројењу за оправку тенкова у близини Санкт Петербурга.

Тенк T-80BVM (2019) представља основу модернизације тенкова серије T-80. Међутим, два су велика недостатка овог тенка: недостају независна панорамска термална осматрачка справа командира идаљински управљане борбене станице (ДУБС). Изостављање ДУБС-а је интересантно решење за тенк који је предвиђен за дејство на Арктику где, због атмосферских прилика, командир не може ефикасно да управља митраљезом. Поред тога, управљање екстерним митраљезом изложило би командира ватреним дејствима и ризицима бојишта.

Недостатак независне панорамске термалне осматрачке справе ограничава улогу командира у тражењу циљева под условима ниске видљивости, што умањује ситуациону свесност посаде тенка.

Равнотежа

Војни планери у Русији морали су да нађу равнотежу између жеља и доступности. Тенкови T-73B3, T-72B3M, T-80BVM, T-90M и T-14 Armata представљају мешовиту флоту са различитим способностима. Јефтиније тенкове могуће је развијати у већим количинама, док се скупља возила дају елитним јединицама. T-80BVM стоји негде у средини свих руских модификација тенкова, а избор мисионих и заштитних система чини возило по његовимкарактеристикама аналогно тенку T-72B3M.

Оба возила располажу модификованим аутоматским пуњачем који прима дужа поткалибарна зрна (APFSDS). T-72B3M је опремљен топом 2A46M-5 који је сличан топу 2A46M4 , а намењен је породици тенкова T-72 и T-90, док је топом 2A46M-4 опремљена серија тенкова T-80. Оба возила имају нишански уређај Sosna-U за нишањџију и уређај TKN-3MK за командира, а слична су по ватреној моћи и ситуационој свесности.

Тенк T-80BVM (2019) има нешто бољу заштиту од тенка T-72B3M, јер поседује ERO типа Relikt на чеоној страни и куполи, док T-72B3M користи старији ERO типа Kontakt-5 на истим местима. Међутим, T-72B3M је опремљен блоковима ERO типа 4S24 Relikt са стране куполе, док на верзији T-80BVM (2019) они нису примећени.

Оба тенка могу имати решеткасти оклоп,као и завесице пуњене са ERO. Дакле, тенкови имају сличну заштиту са бочних страна, али се разликују по чеоним оклопима. Наиме, T-80BVM представља модернизацију серије T-80B/BV којима су шупљине у куполи испуњене

керамичким материјалом „kvartz”, док Т-72В3М задржава куполу тенка Т-72В чији оклоп представља мешавину челика и гуме са неексплозивним реактивним оклопом чиме су попуњене шупљине у куполи. На тај начин купола тенка Т-72В пружа бољу пасивну заштиту против кумулативних пуњења и пенетратора са кинетичком енергијом. Међутим, због употребе старијег ЕРО типа Kontact-5 на куполи тенка Т-72В3М тешко је закључити који тенк има бољу заштиту са чеоне стране.

Поглед на Т-90М: нова купола, командиров ДУБС и бочна заштита.

Тенк Т-80BVM је супериоран по питању мобилности у односу на серију Т-72 захваљујући својој гасној турбини снаге до 1.250 КС. Маса тенка Т-72В3М износи 46,5 т, а покреће га мотор V92S2 снаге до 1.130 КС са мењачем АРР-172. То даје однос снаге и тежину у размери 24.3 КС/т и потенцијалну максималну брзину до 65 км/ч на путу. Иако су ове карактеристике респектабилне и даље су знатно лошије од карактеристика покретљивости тенка Т-80BVM,

Серија Т-80U има другачију куполу од серије Т-80В на којој постоје избочине на куполи које су попуњене модернијом мешавином керамике/полимера/челика ради остваривања боље заштите против напада кумулативних пројектила и кинетичких поткалибарних пенетратора. С друге стране, с обзиром на то да купола тенка Т-80В коју има тенк Т-80BVM садржи керамички материјал „kvartz”, пасивна оклопна заштита на куполи тенка Т-80BVM слабија је у односу на серију Т-80U. Серија Т-80U

опремљена је са ERO типа Kontakt-5 уместо са ERO типа Relikt, знатно су краће завесице на бочним странама, а недостаје им и решеткасти оклоп. Поред тога, ситуациона свесност и ватрена моћ тенка T-80U је инфериорна у односу на T-80BVM, иако је ниво покретљивости оба тенка сличан.

Пакет модернизације тенка T-90M амбициознији је од модернизације тенка T-80BVM. Ипак, оба тенка имају топ 2A46M-5 са редизајнираним аутоматским пуњачем у који стају дужа поткалибарна зрна.

Када се први пут појавила информација о тенку T-90M, многи локални извори су претпоставили да ће бити опремљен истим топом ознаке 2A82-1M као на тенку T-14 Armata, али се то није десило, вероватно због великих трошкова. T-90M има исте заштитне завесице са ERO на бочним странама тенка, као и решеткасти оклоп који се налазе на тенковима T-72B3M и T-80BVM, али је опремљен и мрежом против дејства ручних ракетних бацача преко доњег дела куполе.

Тенк T-90M такође је добио модернизован мотор, V-92S2F снаге 1.130 КС, што му омогућава брзину од 60 км/ч на путевима. Вероватно је да је брзина и већа с обзиром на то да руско министарство одбране наводи да тенк T-90A развија максималну брзину од 60 км/ч са масом од 45,6 тона и мотором снаге од 1.000 КС. Снага мотора тенка T-90M је већа, а маса се процењује на 48 до 50 тона, што би значило већи однос КС/тона, па тиме и већу брзину.

За разлику од тенкова T-72B3M и T-80BVM, T-90M има нову куполу која је опремљена потпуно дигитализованом архитектуром, укључујући дигитални систем за управљање ватром и равне панеле са пројектованом сликом за све чланове посаде. Овај тенк има и независну панорамску осматрачку справу за командира која је интегрисана са даљински управљаном оружном станицом митраљеза 12,7 мм KORD, што омогућава командиру напад на циљеве на већим даљинама и независно гађање меких мета на мањим удаљеностима без потребе окретања куполе.

Локална ситуациона свесност је такође унапређена на тенку T-90M захваљујући систему камера у радијусу од 360 степени. Овај систем укључује камеру на стубу изнад тенка која омогућава ситуациону свесност на мањим даљинама и камеру за вожњу уназад која се укључује када возач убаци мењач за вожњу уназад.

Нишанџија управља нишанским уређајем Sosna-U као и на тенковима T-72B3, T-72B3M и T-80BVM. Поред тога, на тенку T-90M налази се и секундарна телевизијска осматрачка справа, позната као PDT, која има сопствени извор напајања, па је у функцији и када је главни систем напајања у прекиду. Возило је опремљено и унапређеним комуникационим системом који укључује и модерни мрежни радио-уређај из породице R-187 Azart SDR, а вероватно се ради о моделу Azart-BV.

Тенк T-90M има могућност лансирања ваздушнораспрскавајућег пројектила 3VOF128 Tel'nik. Пројектил је развијен на основу руског искуства у Сирији, где су тенковске посаде тражиле могућност ефикасног елиминисања противтенковских тимова.

Упркос бројним предностима, потражња за тенковима Т-14 и даље је мала. Одређени системи тенка пребачени су на тенк Т-90М, као што су ДУБС и одређени делови куполе.

У Евидентно је да тенк Т-90М омогућава бољи комфор посаде:противклизајући слој на трупу тенка, смањује могућност клизања посаде, седишта у куполи су удобнија, а додати су и клима уређај и систем за грејање. Овакве промене први пут су примењене приликом пројектовања тенка Т-14 Armata.

Тенк Т-14 Armata представља врхунац дизајна руских тенкова и, као такав, супериоран је у односу на све модернизоване руске тенкове Т-72/Т-80/Т-90. Тако је достигао стандарде најновијих западних тенкова.

Године 2015. компанија „Uralvagonzavod" навела је да очекује поруџбину од 2.300 тенкова Armata, укључујући Т-14 МВТ, тешко борбено возило пешадије Т-15, као и инжињеријско возило Т-16. Међутим, то се није десило, па је Русија одлучила да уђе у програм јефтиније модернизације своје тенковске флоте. Године 2016. потписала је уговор за прву серију од 100 возила на бази платформе Armata, а затим је следио уговор за 132 возила типа Т-14 и Т-15 током 2018. године.

Цена овог возила повећала се са 320 милиона рубаља (4,6 милиона долара) на 350 милиона рубаља, Овај износ је много већи од суме потребне за модернизацију тенка Т-72В3 која износи око 52 милиона рубаља. Међутим, иако је цена новог возила врло висока, то ипак није главни разлог. Већи проблем за масовније увођење тенка Т-14 у оперативну употребу представљају трошкови резервних делова, логистике, обуке и поправке возила која имају врло мало заједничких делова са постојећим руским тенковима.

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 мултидисциплинарни научни часопис Министарства одбране и Војске Србије. Часопис објављује научне и стручне чланке из области основних истраживања (математике, рачунарских наука и механике) и технолошког развоја (електронике, телекомуникација, информационих технологија, машинства, материјала и хемијских технологија), као и техничке информације о савременим системима наоружања и савременим војним технологијама. Часопис прати јединствену интервидовску техничку подршку Војске на принципу логистичке системске подршке, области основних, примењених и развојних истраживања, као и производњу и употребу средстава наоружања и војне опреме. Часопис објављује и остала теоријска и практична достигнућа која доприносе усавршавању свих припадника српске, регионалне и међународне академске заједнице, а посебно припадника војски и министарстава одбране.

Уређивачка политика Војнотехничког гласника заснива се на препорукама Одбора за етичност у издаваштву (COPE Core Practices), као и на најбољим прихваћеним праксама у научном издаваштву. Војнотехнички гласник је члан COPE (Committee on Publication Ethics) од 2. маја 2018. године.

Министарство просвете, науке и технолошког развоја Републике Србије утврдило је дана 23. 12. 2021. године категоризацију Војнотехничког гласника, за 2021. годину:

- **на листи часописа за рачунарске науке:**
  категорија истакнути национални часопис **(М52)**,
- **на листи часописа за електронику, телекомуникације и информационе технологије:**
  категорија истакнути национални часопис **(М52)**,
- **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 2021. 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) и Руског индекса научног цитирања (РИНЦ). Подвргнут је сталном вредновању (мониторингу) у зависности од утицајности (импакта) у самим базама и, посредно, у међународним (Clarivate Analytics) цитатним индексима. Детаљи о индексирању могу се видети на сајту Војнотехничког гласника, страница *Индексирање часописа*.

Војнотехнички гласник омогућава и примењује Creative Commons (CC BY) одредбе о ауторским правима. Детаљи о ауторским правима могу се видети на сајту часописа, страница *Ауторска права и политика самоархивирања*.

Радови се предају путем онлајн система за електронско уређивање АСИСТЕНТ, који је развио Центар за евалуацију у образовању и науци (ЦЕОН).

Приступ и регистрација за сервис врше се на сајту www.vtg.mod.gov.rs, преко странице *АСИСТЕНТ* или *СЦИНДЕКС*, односно директно на линку aseestant.ceon.rs/index.php/vtg.

Детаљно упутство о регистрацији и пријави за сервис налази се на сајту www.vtg.mod.gov.rs, страница *Упутство за АСИСТЕНТ*.

Потребно је да се сви аутори који подносе рукопис за објављивање у Војнотехничком гласнику региструју у регистар ORCID (Open Researcher and Contributor ID), према упутству на страници сајта *Регистрација за добијање ORCID идентификационе шифре*.

Војнотехнички гласник објављује чланке на енглеском језику (arial, величина слова 11 pt, проред Single).

Поступак припреме, писања и уређивања чланка треба да буде у сагласности са *Изјавом о етичком поступању* (http://www.vtg.mod.gov.rs/izjava-o-etickom-postupanju.html).

Чланак треба да садржи сажетак са кључним речима, увод, разраду, закључак и литературу (без нумерације наслова и поднаслова). Обим чланка треба да буде око једног ауторског табака (16 страница формата А4 са проредом Single), а највише 24 странице.

Чланак треба да буде написан на обрасцу за писање чланка, који се у електронској форми може преузети са сајта на страници *Образац за писање чланка*.

Наслов

Наслов треба да одражава тему чланка. У интересу је часописа и аутора да се користе речи прикладне за индексирање и претраживање. Ако таквих речи нема у наслову, пожељно је да се придода и поднаслов.

Текући наслов

Текући наслов се исписује са стране сваке странице чланка ради лакше идентификације, посебно копија чланака у електронском облику. Садржи презиме и иницијал имена аутора (ако аутора има више, преостали се означавају са „et al.“ или „и др.“), наслове рада и часописа и колацију (година, волумен, свеска, почетна и завршна страница). Наслови часописа и чланка могу се дати у скраћеном облику.

Име аутора

Наводи се пуно име и презиме (свих) аутора. Веома је пожељно да се наведу и средња слова аутора. Имена и презимена домаћих аутора увек се исписују у оригиналном облику (са српским дијакритичким знаковима), независно од језика на којем је написан рад.

Назив установе аутора (афилијација)

Наводи се пун (званични) назив и седиште установе у којој је аутор запослен, а евентуално и назив установе у којој је аутор обавио истраживање. У сложеним организацијама наводи се укупна хијерархија (нпр. Универзитет одбране у Београду, Војна академија, Катедра природно-математичких наука). Бар једна организација у хијерархији мора бити правно лице. Ако аутора има више, а неки потичу из исте установе, мора се, посебним ознакама или на други начин, назначити из које од наведених установа потиче сваки од наведених аутора. Афилијација се исписује непосредно након имена аутора. Функција и звање аутора се не наводе.

Контакт подаци

Адреса или е-адреса свих аутора даје се поред имена и презимена аутора.

Категорија (тип) чланка

Категоризација чланака обавеза је уредништва и од посебне је важности. Категорију чланка могу предлагати рецензенти и чланови уредништва, односно уредници рубрика, али одговорност за категоризацију сноси искључиво главни уредник.

Чланци у *Војнотехничком гласнику* класификују се на научне и стручне чланке.

Научни чланак је:

– оригиналан научни рад (рад у којем се износе претходно необјављени резултати сопствених истраживања научним методом);

– прегледни рад (рад који садржи оригиналан, детаљан и критички приказ истраживачког проблема или подручја у којем је аутор остварио одређени допринос, видљив на основу аутоцитата);

– кратко или претходно саопштење (оригинални научни рад пуног формата, али мањег обима или прелиминарног карактера);

– научна критика, односно полемика (расправа на одређену научну тему, заснована искључиво на научној аргументацији) и осврти.

Изузетно, у неким областима, научни рад у часопису може имати облик монографске студије, као и критичког издања научне грађе (историјско-архивске, лексикографске, библиографске, прегледа података и сл.), дотад непознате или недовољно приступачне за научна истраживања.

Радови класификовани као научни морају имати бар две позитивне рецензије.

Ако се у часопису објављују и прилози ваннаучног карактера, научни чланци треба да буду груписани и јасно издвојени у првом делу свеске.

Стручни чланак је:

– стручни рад (прилог у којем се нуде искуства корисна за унапређење професионалне праксе, али која нису нужно заснована на научном методу);

– информативни прилог (уводник, коментар и сл.);

– приказ (књиге, рачунарског програма, случаја, научног догађаја, и сл.).

Језик рада

Језик рада треба да буде енглески.

Текст мора бити језички и стилски дотеран, систематизован, без скраћеница (осим стандардних). Све физичке величине морају бити изражене у Међународном систему мерних јединица – SI. Редослед образаца (формула) означава се редним бројевима, са десне стране у округлим заградама.

Сажетак

Сажетак јесте кратак информативан приказ садржаја чланка који читаоцу омогућава да брзо и тачно оцени његову релевантност. У интересу је уредништава и аутора да сажетак садржи термине који се често користе за индексирање и претрагу чланака. Саставни делови сажетка су увод/циљ истраживања, методи, резултати и закључак. Сажетак треба да има од 100 до 250 речи и треба да се налази између заглавља (наслов, имена аутора и др.) и кључних речи, након којих следи текст чланка.

Кључне речи

Кључне речи су термини или фразе које адекватно представљају садржај чланка за потребе индексирања и претраживања. Треба их додељивати ослањајући се на неки међународни извор (попис, речник или тезаурус) који је најшире прихваћен или унутар дате научне области. За нпр. науку уопште, то је листа кључних речи Web of Science. Број кључних речи не може бити већи од 10, а у интересу је уредништва и аутора да учесталост њихове употребе буде што већа. У чланку се пишу непосредно након сажетка.

Систем АСИСТЕНТ у ту сврху користи специјалну алатку KWASS: аутоматско екстраховање кључних речи из дисциплинарних тезауруса/речника по избору и рутине за њихов одабир, тј. прихватање односно одбацивање од стране аутора и/или уредника.

Датум прихватања чланка

Датум када је уредништво примило чланак, датум када је уредништво коначно прихватило чланак за објављивање, као и датуми када су у међувремену достављене евентуалне исправке рукописа наводе се хронолошким редоследом, на сталном месту, по правилу на крају чланка.

Захвалница

Назив и број пројекта, односно назив програма у оквиру којег је чланак настао, као и назив институције која је финансирала пројекат или програм, наводи се у посебној напомени на сталном месту, по правилу при дну прве стране чланка.

Претходне верзије рада

Ако је чланак у претходној верзији био изложен на скупу у виду усменог саопштења (под истим или сличним насловом), податак о томе треба да буде наведен у посебној напомени, по правилу при дну прве стране чланка. Рад који је већ објављен у неком часопису не може се објавити у Војнотехничком гласнику (прештампати), ни под сличним насловом и измењеном облику.

Табеларни и графички прикази

Пожељно је да наслови свих приказа, а по могућству и текстуални садржај, буду дати двојезично, на језику рада и на енглеском језику.

Табеле се пишу на исти начин као и текст, а означавају се редним бројевима са горње стране. Фотографије и цртежи треба да буду јасни, прегледни и погодни за репродукцију. Цртеже треба радити у програму word или corel. Фотографије и цртеже треба поставити на жељено место у тексту.

За слике и графиконе не сме се користити снимак са екрана рачунара програма за прикупљање података. У самом тексту чланка препоручује се употреба слика и графикона непосредно из програма за анализу података (као што су Excel, Matlab, Origin, SigmaPlot и други).

Навођење (цитирање) у тексту

Начин позивања на изворе у оквиру чланка мора бити једнообразан.

Војнотехнички гласник за референцирање (цитирање и навођење литературе) примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual). У самом тексту, у обичним заградама, на месту на којем се врши позивање, односно цитирање литературе набројане на крају чланка, обавезно у обичној загради написати презиме цитираног аутора, годину издања публикације из које цитирате и, евентуално, број страница. Нпр. (Petrović, 2012, pp.10–12).

Детаљно упутство о начину цитирања, са примерима, дато је на страници сајта *Упутство за Харвардски приручник за стил*. Потребно је да се позивање на литературу у тексту уради у складу са поменутим упутством.

Систем АСИСТЕНТ у сврху контроле навођења (цитирања) у тексту користи специјалну алатку CiteMatcher: откривање изостављених цитата у тексту рада и у попису референци.

Напомене (фусноте)

Напомене се дају при дну стране на којој се налази текст на који се односе. Могу садржати мање важне детаље, допунска објашњења, назнаке о коришћеним изворима (на пример, научној грађи, приручницима), али не могу бити замена за цитирану литературу.

Листа референци (литература)

Цитирана литература обухвата, по правилу, библиографске изворе (чланке, монографије и сл.) и даје се искључиво у засебном одељку чланка, у виду листе референци. Референце се не преводе на језик рада и набрајају се у посебном одељку на крају чланка.

Војнотехнички гласник, као начин исписа литературе, примењује Харвардски систем референци, односно Харвардски приручник за стил (Harvard Referencing System, Harvard Style Manual).

Литература се обавезно пише на латиничном писму и набраја по абецедном редоследу, наводећи најпре презимена аутора, без нумерације.

Детаљно упутство о начину пописа референци, са примерима, дато је на страници сајта *Упутство за Харвардски приручник за стил*. Потребно је да се попис литературе на крају чланка уради у складу са поменутим упутством.

Нестандардно, непотпуно или недоследно навођење литературе у системима вредновања часописа сматра се довољним разлогом за оспоравање научног статуса часописа.

Систем АСИСТЕНТ у сврху контроле правилног исписа листе референци користи специјалну алатку RefFormatter: контрола обликовања референци у складу са Харвардским приручником за стил.

Изјава о ауторству

Поред чланка доставља се *Изјава о ауторству* у којој аутори наводе свој појединачни допринос у изради чланка. Такође, у тој изјави потврђују да су чланак урадили у складу са *Позивом и упутством ауторима* и *Изјавом о етичком поступању часописа*.

Сви радови подлежу стручној рецензији.

Списак рецензената Војнотехничког гласника може се видети на страници сајта *Списак рецензената*. Процес рецензирања објашњен је на страници сајта *Рецензентски поступак*.

Уредништво

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 мультидисциплинарным научным журналом Министерства обороны и Вооруженных сил Республики Сербия.. В журнале публикуются научные и профессиональные статьи, исследующие такие области как: математика, компьютерные науки и механика, а также области технологического развития: электроника, телекоммуникации, информационные технологии, машиностроение, материалы и химические технологии, в журнале также публикуется: техническая информация о современных системах вооружения и современных военных технологиях. Журнал следит за единой межвидовой технической поддержкой вооруженных сил, основанной на принципах системной логистики, за прикладными и инновационными научными исследованиями, в том числе, в области производства вооружения и военной техники. В журнале публикуются и прочие теоретические и практические достижения, которые способствуют повышению квалификации представителей сербского, регионального и международного академического сообщества, особенно военнослужащих Министерства Обороны и Вооружённых сил.

Редакционная политика журнала «Военно-технический вестник» основана на рекомендациях Комитета по этике научных публикаций (COPE Core Practices), а также на лучшей практике в научно-издательской деятельности. «Военно-технический вестник» является членом COPE со 2 мая 2018 года.

Министерством образования, науки и технологического развития Республики Сербия утверждена 23 декабря 2021 г. категоризация журнала «Военно-технический вестник» за 2021 год:

- **Область компьютерные науки:**
  высококачественный национальный журнал **(M52)**,
- **Область электроники, телекоммуникаций и информационных технологий:**
  высококачественный национальный журнал **(M52)**,
- **Область машиностроения:**
  ведущий журнал государственного значения **(M51)**,
- **Область материалов и химической технологии:**
  ведущий журнал государственного значения **(M51)**.

С информацией относительно категоризации за 2021 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, а также Российского индекса научного цитирования (РИНЦ). Журнал постоянно подвергается мониторингу и оценивается количественными наукометрическими показателями, отражающими его научную ценность, в т.ч. опосредованно в международных индексах цитирования (Clarivate Analytics).

С информацией об индексировании можно ознакомиться на странице сайта журнала *Индексирование Вестника*.

«Военно-технический вестник» обеспечивает читателям возможность открытого доступа, в соответствии с положениями об авторских правах, утверждёнными Creative Commons (CC BY). С инструкцией об авторских правах можно ознакомиться на странице *Авторские права и политика самоархивирования*, перейдя по ссылке http://www.vtg.mod.gov.rs/index-ru.html.

Рукописи статей направляются в редакцию журнала с использованием online системы ASSISTANT, запущенной Центром поддержки развития образования и науки (ЦПРОН).

Регистрация в системе и оформление прав доступа выполняется по адресу http://www.vtg.mod.gov.rs/index-ru.html, через страницу *ASSISTANT* или *СЦИНДЕКС* (aseestant.ceon.rs/index.php/vtg).

С инструкцией по регистрации и правам доступа можно ознакомиться по адресу http://www.vtg.mod.gov.rs/index-ru.html, на странице *Инструкция по ASSISTANT*.

Все авторы, предоставляющие свои рукописи для публикации в редакцию журнала «Военно-технический вестник» должны пройти предварительную регистрацию в реестре ORCID (Open Researcher and Contributor ID). Эта процедура осуществляется в соответствии с инструкцией, размещенной на странице сайта *Регистрация в реестре ORCID для присвоения идентификационного кода*.

«Военно-технический вестник» публикует статьи на английском языке (Arial, шрифт 11 pt, пробел Single).

Процесс подготовки, написания и редактирования статьи должен осуществляться в соответствии с принципами *Этического кодекса* (http://www.vtg.mod.gov.rs/etichyeskiy-kodyeks.html).

Статья должна содержать резюме с ключевыми словами, введение, основную часть, выводы и список использованной литературы (без нумерации заголовков и подзаголовков). Объём статьи не должен превышать один авторский лист (16 страниц формата А4 с пробелом Single).

Статья должна быть набрана на компьютере с использованием специально подготовленного редакцией макета, который можно скачать на странице сайта *Правила и образец составления статьи*.

Заголовок

Заголовок должен отражать тему статьи. В интересах журнала и автора необходимо использовать слова и словосочетания, удобные для индексации и

поиска. Если такие слова не содержатся в заголовке, то желательно их добавить в подзаголовок.

Текущий заголовок

Текущий заголовок пишется в титуле каждой страницы статьи с целью упрощения процесса идентификации, в первую очередь копий статьей в электронном виде. Заголовок содержит в себе фамилию и инициал имени автора (в случае если авторов несколько, остальные обозначаются с «et al.» или «и др.»), название работы и журнала (год, том, выпуск, начальная и заключительная страница). Заголовок статьи и название журнала могут быть приведены в сокращенном виде.

ФИО автора

Приводятся полная фамилия и полное имя (всех) авторов. Желательно, чтобы были указаны инициалы отчеств авторов. Фамилия и имя авторов из Республики Сербия всегда пишутся в оригинальном виде (с сербскими диакритическими знаками), независимо от языка, на котором написана работа.

Наименование учреждения автора (аффилиация)

Приводится полное (официальное) наименование и местонахождение учреждения, в котором работает автор, а также наименование учреждения, в котором автор провёл исследование. В случае организаций со сложной структурой приводится их иерархическая соподчинённость (напр. Военная академия, кафедра военных электронных систем, г. Белград). По крайней мере, одна из организаций в иерархии должна иметь статус юридического лица. В случае если указано несколько авторов, и если некоторые из них работают в одном учреждении, нужно отдельными обозначениями или каким-либо другим способом указать в каком из приведённых учреждений работает каждый из авторов. Аффилиация пишется непосредственно после ФИО автора. Должность и специальность по диплому не указываются.

Контактные данные

Электронный адрес автора указываются рядом с его именем на первой страницы статьи.

Категория (тип) статьи

Категоризация статьей является обязанностью редакции и имеет особое значение. Категорию статьи могут предлагать рецензенты и члены редакции, т.е. редакторы рубрик, но ответственность за категоризацию несет исключительно главный редактор. Статьи в журнале распределяются по следующим категориям:

Научные статьи:

– оригинальная научная статья (работа, в которой приводятся ранее неопубликованные результаты собственных исследований, полученных научным методом);

– обзорная статья (работа, содержащая оригинальный, детальный и критический обзор исследуемой проблемы или области, в который автор внёс определённый вклад, видимый на основе автоцитат);

– краткое сообщение (оригинальная научная работа полного формата, но меньшего объёма или имеющая предварительный характер);

– научная критическая статья (дискуссия-полемика на определённую научную тему, основанная исключительно на научной аргументации) и научный комментарий.

Однако, в некоторых областях знаний научная работа в журнале может иметь форму монографического исследования, а также критического обсуждения научного материала (историко-архивного, лексикографического, библиографического, обзора данных и т.п.) – до сих пор неизвестного или недостаточно доступного для научных исследований. Работы, классифицированные в качестве научных, должны иметь, по меньшей мере, две положительные рецензии.

В случае если в журнале объявляются и приложения, не имеющие научный характер, научные статьи должны быть сгруппированы и четко выделены в первой части номера.

Профессиональные статьи:

– профессиональная работа (приложения, в которых предлагаются опыты, полезные для совершенствования профессиональной практики, но которые не должны в обязательном порядке быть обоснованы на научном методе);

– информативное приложение (передовая статья, комментарий и т.п.);

– обзор (книги, компьютерной программы, случая, научного события и т.п.).

Язык работы

Статья должна быть написана на английском языке.

Текст должен быть в лингвистическом и стилистическом смысле упорядочен, систематизирован, без сокращений (за исключением стандартных). Все физические величины должны соответствовать Международной системе единиц измерения – СИ. Очередность формул обозначается порядковыми номерами, проставляемыми с правой стороны в круглых скобках.

Резюме

Резюме является кратким информативным обзором содержания статьи, обеспечивающим читателю быстроту и точность оценки её релевантности. В интересах редакции и авторов, чтобы резюме содержало термины, часто используемые для индексирования и поиска статьей. Составными частями резюме являются введение/цель исследования, методы, результаты и выводы. В резюме должно быть от 100 до 250 слов, и оно должно находится между титулами (заголовок, ФИО авторов и др.) и ключевыми словами, за которыми следует текст статьи.

Ключевые слова

Ключевыми словами являются термины или фразы, адекватно представляющие содержание статьи, необходимые для индексирования и поиска. Ключевые слова необходимо выбирать, опираясь при этом на какой-либо международный источник (регистр, словарь, тезаурус), наиболее используемый внутри данной научной области. Число ключевых слов не может превышать 10. В интересах редакции и авторов, чтобы частота их встречи в статье была как можно большей. В статье они пишутся непосредственно после резюме.

Программа ASSISTANT предоставляет возможность использования сервиса KWASS, автоматически фиксирующего ключевые слова из источников/словарей по выбору автора/редактора.

Дата получения статьи

Дата, когда редакция получила статью; дата, когда редакция окончательно приняла статью к публикации; а также дата, когда были предоставлены необходимые исправления рукописи, приводятся в хронологическом порядке, как правило, в конце статьи.

Выражение благодарности

Наименование и номер проекта, т.е. название программы благодаря которой статья возникла, совместно с наименованием учреждения, которое финансировало проект или программу, приводятся в отдельном примечании, как правило, внизу первой страницы статьи.

Предыдущие версии работы

В случае если статья в предыдущей версии была изложена устно (под одинаковым или похожим названием, например, в виде доклада на научной конференции), сведения об этом должны быть указаны в отдельном примечании, как правило, внизу первой страницы статьи. Работа, которая уже была опубликована в каком-либо из журналов, не может быть напечатана в «Военно-техническом вестнике» ни под похожим названием, ни в изменённом виде.

Нумерация и название таблиц и графиков

Желательно, чтобы нумерация и название таблиц и графиков были исполнены на двух языках (на языке оригинала и на английском). Таблицы подписываются таким же способом как и текст и обозначаются порядковым номером с верхней стороны. Фотографии и рисунки должны быть понятны, наглядны и удобны для репродукции. Рисунки необходимо делать в программах Word или Corel. Фотографии и рисунки надо поставить на желаемое место в тексте. Для создания изображений и графиков использование функции снимка с экрана (скриншота) не допускается. В самом тексте статьи рекомендуется применение изображений и графиков, обработанных такими компьютерными программами, как: Excel, Matlab, Origin, SigmaPlot и др.

Ссылки (цитирование) в тексте

Оформление ссылок на источники в рамках статьи должно быть однообразным. «Военно-технический вестник» для оформления ссылок, цитат и списка использованной литературы применяет Гарвардскую систему (Harvard Referencing System, Harvard Style Manual). В тексте в скобках приводится фамилия цитируемого автора (или фамилия первого автора, если авторов несколько), год издания и по необходимости номер страницы. Например: (Petrović, 2010, pp.10-20). Рекомендации о способе цитирования размещены на странице сайта *Инструкция по использованию Гарвардского стиля*. При оформлении ссылок, цитат и списка использованной литературы необходимо придерживаться установленных норм. Программа ASSISTANT предоставляет при цитировании возможность использования сервиса CiteMatcher, фиксирующего пропущенные цитаты в работе и в списке литературы.

Примечания (сноски)

Примечания (сноски) к тексту указываются внизу страницы, к которой они относятся. Примечания могут содержать менее важные детали, дополнительные объяснения, указания об использованных источниках (напр. научном материале, справочниках), но не могут быть заменой процедуры цитирования литературы.

Литература (референции)

Цитированной литературой охватываются, как правило, такие библиографические источники как статьи, монографии и т.п. Вся используемая литература в виде референций размещается в отдельном разделе статьи.

Названия литературных источников не переводятся на язык работы.

«Военно-технический вестник» для оформления списка использованной литературы применяет Гарвардскую систему (Harvard Style Manual). В списке литературы источники указываются в алфавитном порядке фамилий авторов или редакторов. Рекомендации о способе цитирования размещены на странице сайта *Инструкция по использованию Гарвардского стиля*. При оформлении списка использованной литературы необходимо придерживаться установленных норм.

При оформлении списка литературы программа ASSISTANT предоставляет возможность использования сервиса RefFormatter, осуществляющего контроль оформления списка литературы в соответствии со стандартами Гарвардского стиля.

Нестандартное, неполное и непоследовательное приведение литературы в системах оценки журнала считается достаточной причиной для оспаривания научного статуса журнала.

Авторское заявление

Авторское заявление предоставляется вместе со статьей, в нем авторы заявляют о своем личном вкладе в написание статьи. В заявлении авторы подтверждают, что статья написана в соответствии с *Приглашением и инструкциями для авторов*, а также с *Кодексом профессиональной этики журнала*.

Все рукописи статей подлежат профессиональному рецензированию.

Список рецензентов журнала «Военно-технический вестник» размещён на странице сайта *Список рецензентов*. Процесс рецензирования описан в разделе *Правила рецензирования*.

Редакция

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 a multidisciplinary scientific journal of the Ministry of Defence and the Serbian Armed Forces. The journal publishes scientific and professional papers covering fundamental research (mathematics, computer science and mechanics) and technological development (electronics, telecommunications, information technologies, mechanical engineering, material science and chemical technologies) as well as technical data on modern weapon systems and military technologies. The journal covers inter-service technical support to the Army on the principle of logistic system support; fundamental, applied and development research; production and use of weapons and military equipment. Also, the journal publishes other theoretical and practical achievements leading to professional development of all members of Serbian, regional and international academic communities as well as members of the military and ministries of defence in particular.

The editorial policy of the Military Technical Courier is based on the COPE Core Practices and the journal articles are consistent with accepted best practices in their subject areas. As of 2 May 2018, the Military Technical Courier is a member of COPE (Committee on Publication Ethics).

The Ministry of Education, Science and Technological Development of the Republic of Serbia classified the Military Technical Courier for the year 2021, on December 23, 2021

- **on the list of periodicals for computer sciences,**
  category: quality national journal **(M52)**,
- **on the list of periodicals for electronics, telecommunications and IT,**
  category: quality national journal **(M52)**,
- **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 2021 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 Russian Index of Science Citation/Российский индекс научного цитирования (RINC/РИНЦ) and is constantly monitored depending on the impact within the bases themselves and indirectly in the international (e.g. Clarivate Analytics) citation indexes. More detailed information can be viewed on the website of the Military Technical Courier, page *Journal indexing*.

Military Technical Courier enables open access and applies the Creative Commons Attribution (CC BY) licence provisions on copyright. The copyright details can be found on the *Copyright notice 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 the abstract with keywords, introduction, body, conclusion and references (without heading and subheading enumeration). The article length should not exceed 24 pages of A4 paper format.

The article should be formatted following the instructions in the Article Form which can be downloaded from website page *Article form*.

Title

The title should be informative. It is in both Journal's and author's best interest to use terms suitable for indexing and word search. If there are no such terms in the title, the author is strongly advised to add a subtitle.

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.)

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

ОБАВЕШТЕЊА САРАДНИЦИМА И ЧИТАОЦИМА
СООБЩЕНИЯ ДЛЯ АВТОРОВ И ЧИТАТЕЛЕЙ
INFORMATION FOR CONTRIBUTORS AND READERS

Министарство просвете, науке и технолошког развоја Републике Србије објавило категоризацију „Војнотехничког гласника” за 2021. годину

Министарство просвете, науке и технолошког развоја Републике Србије, сагласно Правилнику о категоризацији и рангирању научних часописа („Службени гласник РС”, број 159/20), утврдило је дана 23. 12. 2021. године категоризацију „Војнотехничког гласника” за 2021. годину:

- **на листи часописа за рачунарске науке**:
  категорија истакнути национални часопис **(M52)**,
- **на листи часописа за електронику, телекомуникације и информационе технологије**:
  категорија истакнути национални часопис **(M52)**,
- **на листи часописа за машинство**:
  категорија врхунски часопис националног значаја **(M51)**,
- **на листи часописа за материјале и хемијске технологије**:
  категорија врхунски часопис националног значаја **(M51)**.

Усвојене листе домаћих часописа за 2021. годину могу се видети на страници сајта *Категоризација часописа* (http://www.vtg.mod.gov.rs/kategorizacija-casopisa.html).

Детаљније информације могу се пронаћи и на сајту Министарства просвете, науке и технолошког развоја Републике Србије (https://mpn.gov.rs/nauka/nauka-i-istrazivanje-u-srbiji/kategorizacija-naucnih-casopisa/).

Министерство образования, науки и технологического развития Республики Сербия утвердило категоризацию журнала «Военно-технический вестник» за 2021 год

Министерством образования, науки и технологического развития Республики Сербия, согласно Регламенту о категоризации и ранжировании научных журналов («Службени гласник РС», № 159/20), утверждена 23 декабря 2021 г. категоризация журнала «Военно-технический вестник» за 2021 год:

– **Область компьютерные науки**:
высококачественный национальный журнал **(M52)**,
– **Область электроники, телекоммуникаций и информационных технологий**:
высококачественный национальный журнал **(M52)**,
– **Область машиностроения**:
ведущий журнал государственного значения **(M51)**,
– **Область материалов и химической технологии**:
ведущий журнал государственного значения **(M51)**.

С информацией о категоризации за 2021 год можно ознакомиться на странице *Категоризация вестника* (http://www.vtg.mod.gov.rs/kategorizacia-vestnika.html).

Более подробно с информацией можно ознакомиться на сайте Министерства образования, науки и технологического развития Республики Сербия (https://mpn.gov.rs/nauka/nauka-i-istrazivanje-u-srbiji/kategorizacija-naucnih-casopisa/).

Ministry of Education, Science and Technological Development of the Republic of Serbia classified the Military Technical Courier for the year 2021

Pursuant to the Regulations on categorization and ranking of scientific journals (Official Gazette of the Republic of Serbia, No 159/20), the Ministry of Education, Science and Technological Development of the Republic of Serbia classified the Military Technical Courier for the year 2021, on December 23, 2021

– **on the list of periodicals for computer sciences**,
category: quality national journal **(M52)**,
– **on the list of periodicals for electronics, telecommunications and IT**,
category: quality national journal **(M52)**,
– **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 2021 can be viewed on the web page *Journal categorization* (http://www.vtg.mod.gov.rs/journal-categorisation-1.html).

More detailed information can be found on the website of the Ministry of Education, Science and Technological Development of the Republic of Serbia (https://mpn.gov.rs/nauka/nauka-i-istrazivanje-u-srbiji/kategorizacija-naucnih-casopisa/).

СПИСАК РЕЦЕНЗЕНАТА ВОЈНОТЕХНИЧКОГ ГЛАСНИКА
СПИСОК РЕЦЕНЗЕНТОВ ЖУРНАЛА «ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК»
LIST OF REFEREES OF THE MILITARY TECHNICAL COURIER

СПИСАК РЕЦЕНЗЕНАТА *ВОЈНОТЕХНИЧКОГ ГЛАСНИКА*

Име, средње слово и презиме	**Област компетенције (научног интересовања)**	**ORCID iD**	**Publons identifier**
Марко Д. Андрејић	логистика	https://orcid.org/0000-0002-6753-9786	https://publons.com/a/1597995
Милош Ж. Арсић	логистички менаџмент	https://orcid.org/0000-0001-7853-0819	https://publons.com/a/1604531
Ђорђе Б. Баралић	алгебарска топологија, геометрија и комбинаторика	https://orcid.org/0000-0003-2836-7958	https://publons.com/a/3574650
Саша Т. Бакрач	заштита животне средине, процена еколошких ризика, екоменаџмент	https://orcid.org/0000-0003-0211-3765	https://publons.com/a/1597282
Војислав Ј. Батинић	опште машинске конструкције	https://orcid.org/0000-0001-6786-7846	https://publons.com/a/1643029
Драгана Бечејски-Вујаклија	пословни информациони системи, пословна интелигенција, ERP, IT менаџмент	https://orcid.org/0000-0002-9615-3620	https://publons.com/a/1623502
Дарко И. Божанић	вишекритеријумско одлучивање, менаџмент у одбрани	https://orcid.org/0000-0002-9657-0889	https://publons.com/a/1524010
Мирко А. Борисов	геодетско инжењерство, геоматика, географски информациони системи, дигитални модели терена, картографија, геодезија, мултимедијална картографија, веб картографија	https://orcid.org/0000-0002-7234-6372	https://publons.com/a/1613254
Угљеша С. Бугарић	операц. истраживања, масовно опслуживање, теротехнологија-одржавање, транспортни и складишни системи	https://orcid.org/0000-0003-2459-2656	https://publons.com/a/1596666

Име, средње слово и презиме	Област компетенције (научног интересовања)	ORCID iD	Publons identifier
Славиша И. Влачић	ваздушни саобраћај, системска контрола; аутоматска контрола; навигација возила; морнарички борбени и навигациони системи; симулација	https://orcid.org/0000-0001-9336-0512	https://publons.com/a/1604062
Драгољуб А. Вујић	примењена механика, дијагностика, софистицирани системи одржавања техничких система	https://orcid.org/0000-0001-6999-6828	https://publons.com/a/1627346
Иван Б. Вулић	информациони системи, географски информациони системи	https://orcid.org/0000-0002-5161-5422	https://publons.com/a/1606268
Љубомир Ј Гиговић	географија, географски информациони систем, геопросторна анализа	https://orcid.org/0000-0002-8388-3624	https://publons.com/a/1418283
Миро Ј. Говедарица	геоинформатика	https://orcid.org/0000-0003-1698-0800	https://publons.com/a/1539597
Горан Д. Дикић	системи аутоматског управљања, праћење циљева, системи вођења и управљања ракета	https://orcid.org/0000-0002-0858-1415	https://publons.com/a/1634756
Снежана М. Драгићевић	енергетска ефикасност, машинство, соларна енергија, термоинжењеринг	https://orcid.org/0000-0002-6244-0111	https://publons.com/a/1604121
Чедомир В. Дубока	мотори, моторна возила	https://orcid.org/0000-0003-2944-2278	https://publons.com/a/1627827
Бобан Д. Ђоровић	процеси и методе у саобраћају и транспорту, транспортне мреже, организација транспорта	https://orcid.org/0000-0001-8133-2389	https://publons.com/a/1633020
Владо П. Ђурковић	примењена механика крутог и деформабилног тела	https://orcid.org/0000-0002-5064-4117	https://publons.com/a/1622194
Дејан Р. Инђић	тактика АБХ службе, оружје за масовно уништавање, тероризам оружјем за масовно уништавање, нуклеарни и хемијски удеси	https://orcid.org/0000-0001-9111-0472	https://publons.com/a/1616130

Име, средње слово и презиме	Област компетенције (научног интересовања)	ORCID iD	Publons identifier
Дамир Д. Јерковић	наоружање, нумеричка анализа, CFD симулација, спољна балистика, балистика, балистика на циљу, интеграција наоружања	https://orcid.org/0000-0001-5182-7057	https://publons.com/a/1500127
Бориша Ж. Јовановић	информационе технологије, софтверско инжењерство, безбедност рачунарских система, рачунарске мреже	https://orcid.org/0000-0002-9353-724X	https://publons.com/a/3851268
Митар Т. Јоцановић	трибологија и теорија подмазивања, одржавање технолошких система, хидраулички системи	https://orcid.org/0000-0003-1088-5028	https://publons.com/a/1596778
Владимир А. Катић	енергетска електроника, електричне машине, електромоторни погони, квалитет електричне енергије, обновљиви извори електричне енергије	https://orcid.org/0000-0002-0138-8807	https://publons.com/a/1318533
Мирко С. Козић	механика флуида, нумеричка динамика флуида, аеродинамичка оптерећења	https://orcid.org/0000-0002-7287-0780	https://publons.com/a/1627334
Комлен Г. Лаловић	информационе технологије, програмирање, заштита података	https://orcid.org/0000-0002-4590-2185	https://publons.com/a/1610913
Марија З. Малнар	електротехника, телекомуникације	https://orcid.org/0000-0003-1416-8253	https://publons.com/a/3269205

Име, средње слово и презиме	Област компетенције (научног интересовања)	ORCID iD	Publons identifier
Зоран Ђ. Миљковић	технологија машинске обраде, роботика, вештачка интелигенција, аутономни системи и машинско учење, вештачке неуронске мреже, интелигентни технолошки системи и процеси, методе одлучивања	https://orcid.org/0000-0001-9706-6134	https://publons.com/a/1410489
Надица С. Миљковић	биомедицинска обрада сигнала, е-здравље, електротехника, биомедицински инжењеринг, електрофизиологија	https://orcid.org/0000-0002-3933-6076	https://publons.com/a/1628814
Срђан Т. Митровић	мобилни роботи, управљање у реалном времену, фази логика, фази управљање, микропроцесорски системи, управљање системима (аутоматика), алгоритми навигације возила, бродски борбени и навигациони системи	https://orcid.org/0000-0002-1287-2792	https://publons.com/a/1467408
Дејан М. Мицковић	конструкција класичног наоружања, аутоматска оружја, унутрашња балистика	/	/
Драган Д. Младеновић	информациона безбедност, сајбер безбедност, сајбер сукоби, сајбер ратовање, информационе технологије, међународно право, нове технологије	https://orcid.org/0000-0003-4530-633X	https://publons.com/a/1604465
Бобан З. Павловић	телекомуникационе мреже, квалитет сервиса, телекомуникациони саобраћај	https://orcid.org/0000-0002-5476-7894	https://publons.com/a/1606407
Сретен Р. Перић	машинство	https://orcid.org/0000-0002-7270-5187	https://publons.com/a/1620400

Име, средње слово и презиме	Област компетенције (научног интересовања)	ORCID iD	Publons identifier
Мирослав В. Поповић	рачунарска техника	https://orcid.org/0000-0002-1118-6491	https://publons.com/a/1558230
Југослав Р. Радуловић	муниција, менаџмент, квалитет	https://orcid.org/0000-0002-4003-7209	https://publons.com/a/1611389
Влада С. Соколовић	одржавање, техничка подршка, интегрисани навигацијски системи, GPS, GNSS, сателитски системи, логистика	https://orcid.org/0000-0003-0782-0506	https://publons.com/a/1559198
Наем Салем	математика	https://orcid.org/0000-0002-1485-6163	https://publons.com/a/1716462
Љубиша К. Танчић	унутрашња балистика, наоружање	https://orcid.org/0000-0003-1242-9333	https://publons.com/a/1623091
Иван А. Тот	базе података, информациони системи, заштита информационих система	https://orcid.org/0000-0002-5862-9042	https://publons.com/a/1558155
Обрад Т. Чабаркапа	индустријска својина, заштита интелектуалне и индустријске својине, патентна заштита, управљање пројектима, машинство, наоружање, пројект менаџмент	https://orcid.org/0000-0002-3949-8227	https://publons.com/a/1600393
Нада М. Читаковић	физика	https://orcid.org/0000-0003-2813-2323	https://publons.com/a/1601584
Томислав Б. Шекара	управљање процесима; оптимални индустријски регулатори; фракциони закони управљања; дискретизација и обрада сигнала; сензори и актуатори	https://orcid.org/0000-0001-8031-3135	https://publons.com/a/1596795
Горан П. Шимић	информациони системи, рачунарство, програмирање, базе података, вештачка интелигенција	https://orcid.org/0000-0002-7563-699X	https://publons.com/a/1600386

СПИСОК РЕЦЕНЗЕНТОВ ЖУРНАЛА *«ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК»*

ФИО	Области научной деятельности	ORCID iD	Publons identifier
Марко Д. Андреич	логистика	https://orcid.org/0000-0002-6753-9786	https://publons.com/a/1597995
Милош Ж. Арсич	управление логистикой	https://orcid.org/0000-0001-7853-0819	https://publons.com/a/1604531
Джордже Б. Баралич	алгебраическая топология, геометрия и комбинаторика	https://orcid.org/0000-0003-2836-7958	https://publons.com/a/3574650
Саша Т. Бакрач	охрана окружающей среды, оценка экологических рисков, экологический менеджмент	https://orcid.org/0000-0003-0211-3765	https://publons.com/a/1597282
Воислав Й. Батинич	общие машиностроительные конструкции	https://orcid.org/0000-0001-6786-7846	https://publons.com/a/1643029
Драгана Бечейски-Вуяклия	бизнес-информационные системы, бизнес-аналитика, ERP, управление ИТ	https://orcid.org/0000-0002-9615-3620	https://publons.com/a/1623502
Дарко И. Божанич	принятие многокритериальных решений, управление в области обороны	https://orcid.org/0000-0002-9657-0889	https://publons.com/a/1524010
Мирко А. Борисов	геодезическая инженерия, геоматика, геоинформационные системы, цифровые модели местности, картография, геодезия, мультимедийная картография, веб-картография	https://orcid.org/0000-0002-7234-6372	https://publons.com/a/1613254
Углеша С. Бугарич	исследование операций, теория массового обслуживания, теротехнология обслуживания, транспортно-складские системы	https://orcid.org/0000-0003-2459-2656	https://publons.com/a/1596666

ФИО	Области научной деятельности	ORCID iD	Publons identifier
Славиша И. Влачич	воздушное движение, управление системой; автоматическое управление; автомобильная навигация; морские боевые и навигационные системы; моделирование	https://orcid.org/0000-0001-9336-0512	https://publons.com/a/1604062
Драголюб А. Вуич	прикладная механика, диагностика, сложные системы технического обслуживания	https://orcid.org/0000-0001-6999-6828	https://publons.com/a/1627346
Иван Б. Вулич	информационные системы, географические информационные системы	https://orcid.org/0000-0002-5161-5422	https://publons.com/a/1606268
Любомир Й. Гигович	география, географическая информационная система, геопространственный анализ	https://orcid.org/0000-0002-8388-3624	https://publons.com/a/1418283
Миро Й. Говедарица	геоинформатика	https://orcid.org/0000-0003-1698-0800	https://publons.com/a/1539597
Бобан Д. Джорович	транспортные процессы и методы, транспортные сети, организация транспорта	https://orcid.org/0000-0001-8133-2389	https://publons.com/a/1633020
Владо П. Джуркович	прикладная механика твердых и деформируемых тел	https://orcid.org/0000-0002-5064-4117	https://publons.com/a/1622194
Горан Д. Дикич	системы автоматического управления, прицеливания, системы наведения и телеуправления ракет	https://orcid.org/0000-0002-0858-1415	https://publons.com/a/1634756
Снежана М. Драгичевич	энергоэффективность, машиностроение, солнечная энергия, теплотехника термоинженерия	https://orcid.org/0000-0002-6244-0111	https://publons.com/a/1604121

ФИО	Области научной деятельности	ORCID iD	Publons identifier
Чедомир В. Дубока	двигатели, автомобили	https://orcid.org/0000-0003-2944-2278	https://publons.com/a/1627827
Дамир Д. Еркович	вооружение, численный анализ, CFD вычислительная гидродинамика, внешняя баллистика, баллистика, терминальная баллистика, интегрирование вооружения	https://orcid.org/0000-0001-5182-7057	https://publons.com/a/1500127
Деян Р. Инджич	тактика ядерно-химической биологической защиты, оружие массового уничтожения, терроризм с оружием	https://orcid.org/0000-0001-9111-0472	https://publons.com/a/1616130
Бориша Ж. Йованович	информационные технологии, программная инженерия, безопасность компьютерных систем, компьютерные сети	https://orcid.org/0000-0002-9353-724X	https://publons.com/a/3851268
Митар Т. Йоцанович	трибология и теория смазки, техническое обслуживание технологических систем, гидравлических систем	https://orcid.org/0000-0003-1088-5028	https://publons.com/a/1596778
Владимир А. Катич	силовая электроника, электрические машины, электрические приводы, качество электроэнергии, возобновляемые источники энергии	https://orcid.org/0000-0002-0138-8807	https://publons.com/a/1318533
Мирко С. Козич	механика жидкостей, вычислительная динамика жидкостей, аэродинамические нагрузки	https://orcid.org/0000-0002-7287-0780	https://publons.com/a/1627334
Комлен Г. Лалович	информационные технологии, программирование, защита данных	https://orcid.org/0000-0002-4590-2185	https://publons.com/a/1610913
Мария З. Малнар	электротехника, телекоммуникации	https://orcid.org/0000-0003-1416-8253	https://publons.com/a/3269205
Зоран Дж. Милькович	технология производства, процессы обработки, робототехника,	https://orcid.org/0000-0001-9706-6134	https://publons.com/a/1410489

ФИО	Области научной деятельности	ORCID iD	Publons identifier
	искусственный интеллект, автономные системы и машинное обучение, искусственные нейронные сети, интеллектуальные производственные системы и процессы, принятие решений		
Надица С. Милкович	обработка биомедицинских сигналов, электронное здравоохранение, электротехника, биомедицинская инженерия, электрофизиология	https://orcid.org/0000-0002-3933-6076	https://publons.com/a/1628814
Срджан Т. Митрович	мобильные роботы, управление в реальном времени, нечеткая логика, нечеткое управление, микропроцессорные системы, управление системами автоматики, алгоритмы навигации транспорта, навигационные системы для судов и боевого транспорта	https://orcid.org/0000-0002-1287-2792	https://publons.com/a/1467408
Деян М. Мицкович	конструкция классического конвенционального вооружения, автоматическое оружие, внутренняя баллистика	/	/
Драган, Д. Младенович	информационная безопасность, кибербезопасность, кибер-конфликт, кибер-война, информационные технологии, международное право	https://orcid.org/0000-0003-4530-633X	https://publons.com/a/1604465
Бобан З. Павлович	телекоммуникационные сети, качество обслуживания, телекоммуникационный трафик	https://orcid.org/0000-0002-5476-7894	https://publons.com/a/1606407
Сретен Р. Перич	машиностроение	https://orcid.org/0000-0002-7270-5187	https://publons.com/a/1620400

ФИО	Области научной деятельности	ORCID iD	Publons identifier
Мирослав В. Попович	компьютерная инженерия	https://orcid.org/0000-0002-1118-6491	https://publons.com/a/1558230
Югослав Р. Радулович	боеприпасы, менеджмент, качество	https://orcid.org/0000-0002-4003-7209	https://publons.com/a/1611389
Наем Салем	математика	https://orcid.org/0000-0002-1485-6163	https://publons.com/a/1716462
Влада С. Соколович	техническое обслуживание, техническая поддержка, интегрированные навигационные системы, GPS, GNSS, спутниковые системы, логистика	https://orcid.org/0000-0003-0782-0506	https://publons.com/a/1559198
Любиша К. Танчич	внутренняя баллистика, вооружение	https://orcid.org/0000-0003-1242-9333	https://publons.com/a/1623091
Иван А. Тот	базы данных, информационные системы, защита информационных систем	https://orcid.org/0000-0002-5862-9042	https://publons.com/a/1558155
Обрад Т. Чабаркапа	промышленная собственность, защита интеллектуальной и промышленной собственности, патентная защита, управление проектами, машиностроение, вооружение, управление проектами	https://orcid.org/0000-0002-3949-8227	https://publons.com/a/1600393
Нада М. Читакович	физика	https://orcid.org/0000-0003-2813-2323	https://publons.com/a/1601584
Томислав Б. Шекара	управление процессами, оптимальные промышленные регуляторы, дискретизация и обработка сигналов, сенсоры и актуаторы, компенсация электроэнергии в электроэнергетических системах	https://orcid.org/0000-0001-8031-3135	https://publons.com/a/1596795
Горан П. Шимич	информационные системы, информатика, программирование, базы данных, искусственный интеллект	https://orcid.org/0000-0002-7563-699X	https://publons.com/a/1600386

LIST OF REFEREES OF THE MILITARY TECHNICAL COURIER

Name, middle initial and surname	Scientific research competence area	ORCID iD	Publons identifier
Marko D. Andrejić	logistics	https://orcid.org/0000-0002-6753-9786	https://publons.com/a/1597995
Miloš Ž. Arsić	logistics management	https://orcid.org/0000-0001-7853-0819	https://publons.com/a/1604531
Đorđe B. Baralić	algebraic topology, geometry and combinatorics	https://orcid.org/0000-0003-2836-7958	https://publons.com/a/3574650
Saša T. Bakrač	environmental protection, environmental risk assessment, eco-management	https://orcid.org/0000-0003-0211-3765	https://publons.com/a/1597282
Vojislav J. Batinić	general mechanical engineering constructions	https://orcid.org/0000-0001-6786-7846	https://publons.com/a/1643029
Dragana Bečejski-Vujaklija	business information systems, business intelligence, ERP, IT management	https://orcid.org/0000-0002-9615-3620	https://publons.com/a/1623502
Mirko A. Borisov	geodetic engineering, geomatics, geographic information systems, digital terrain models, cartography, geodesy, multimedia cartography, web mapping	https://orcid.org/0000-0002-7234-6372	https://publons.com/a/1613254
Darko I. Božanić	multi-criteria decision making, management in defense	https://orcid.org/0000-0002-9657-0889	https://publons.com/a/1524010
Uglješa S. Bugarić	operational research, mass service, terotechnology – maintenance, transportation and storage systems	https://orcid.org/0000-0003-2459-2656	https://publons.com/a/1596666
Obrad T. Čabarkapa	industrial property, protection of intellectual and industrial property, patent protection, project management, mechanical engineering, armaments, project management	https://orcid.org/0000-0002-3949-8227	https://publons.com/a/1600393
Nada M. Čitaković	physics	https://orcid.org/0000-0003-2813-2323	https://publons.com/a/1601584
Goran D. Dikić	automatic control systems, target tracking, missile guidance and control systems	https://orcid.org/0000-0002-0858-1415	https://publons.com/a/1634756

Name, middle initial and surname	Scientific research competence area	ORCID iD	Publons identifier
Snežana M. Dragićević	energy efficiency, mechanical engineering, solar energy, thermal engineering	https://orcid.org/0000-0002-6244-0111	https://publons.com/a/1604121
Čedomir V. Duboka	engines, motor vehicles	https://orcid.org/0000-0003-2944-2278	https://publons.com/a/1627827
Boban D. Đorović	processes and methods in traffic and transportation, transportation networks, transport organization	https://orcid.org/0000-0001-8133-2389	https://publons.com/a/1633020
Vlado P. Đurković	applied mechanics of rigid and deformable bodies	https://orcid.org/0000-0002-5064-4117	https://publons.com/a/1622194
Ljubomir J. Gigović	geography, geographic information system, geospatial analysis	https://orcid.org/0000-0002-8388-3624	https://publons.com/a/1418283
Miro J. Govedarica	geoinformatics	https://orcid.org/0000-0003-1698-0800	https://publons.com/a/1539597
Dejan R. Inđić	tactic of Nuclear Chemical Biological Defense, weapons of mass destruction, terrorism with weapons of mass destruction, nuclear and chemical incidents	https://orcid.org/0000-0001-9111-0472	https://publons.com/a/1616130
Damir D. Jerković	weapons, numerical analysis, CFD simulation, external ballistics, ballistics, terminal ballistics, weapons integration	https://orcid.org/0000-0001-5182-7057	https://publons.com/a/1500127
Mitar T. Jocanović	tribology and theory of lubrication, maintenance of technological systems, hydraulic systems	https://orcid.org/0000-0003-1088-5028	https://publons.com/a/1596778
Boriša Ž. Jovanović	IT, software engineering, computer systems security, computer networks	https://orcid.org/0000-0002-9353-724X	https://publons.com/a/3851268
Vladimir A. Katić	power electronics, electric machines, electric power systems and stations, electric power quality, renewable energy sources	https://orcid.org/0000-0002-0138-8807	https://publons.com/a/1318533
Mirko S. Kozić	mechanics of fluids, computational fluid dynamics, aerodynamic load	https://orcid.org/0000-0002-7287-0780	https://publons.com/a/1627334

Name, middle initial and surname	Scientific research competence area	ORCID iD	Publons identifier
Komlen G. Lalović	information technology, programming, data protection	https://orcid.org/0000-0002-4590-2185	https://publons.com/a/1610913
Marija Z. Malnar	electrical engineering - telecommunications	https://orcid.org/0000-0003-1416-8253	https://publons.com/a/3269205
Dejan M. Micković	construction of classic weapons, automatic weapons, internal ballistics	/	/
Nadica S. Miljković	biomedical signal processing, e-health, electrical engineering, biomedical engineering, electrophysiology	https://orcid.org/0000-0002-3933-6076	https://publons.com/a/1628814
Zoran Đ. Miljković	manufacturing technology, machining processes, robotics, artificial intelligence, autonomous systems and machine learning, artificial neural networks, intelligent manufacturing systems and processes, decision-making methods	https://orcid.org/0000-0001-9706-6134	https://publons.com/a/1410489
Srđan T. Mitrović	mobile robots, real time control, fuzzy logic, fuzzy control, microprocessing systems, system control (automation), vehicle navigation algorithms, naval combat and navigation systems	https://orcid.org/0000-0002-1287-2792	https://publons.com/a/1467408
Dragan D. Mladenović	information security, cyber security, cyber conflict, cyber warfare, information technology, international law, emerging technologies	https://orcid.org/0000-0003-4530-633X	https://publons.com/a/1604465
Boban Z. Pavlović	telecommunication networks, quality of service, telecommunication traffic	https://orcid.org/0000-0002-5476-7894	https://publons.com/a/1606407
Sreten R. Perić	mechanical engineering	https://orcid.org/0000-0002-7270-5187	https://publons.com/a/1620400
Miroslav V. Popović	computer engineering	https://orcid.org/0000-0002-1118-6491	https://publons.com/a/1558230
Jugoslav R. Radulović	ammunition, management, quality	https://orcid.org/0000-0002-4003-7209	https://publons.com/a/1611389
Naeem Saleem	mathematics	https://orcid.org/0000-0002-1485-6163	https://publons.com/a/1716462

Name, middle initial and surname	Scientific research competence area	ORCID iD	Publons identifier
Vlada S. Sokolović	maintenance, technical support, integrated navigation systems, GPS, GNSS, satellite systems, logistics	https://orcid.org/0000-0003-0782-0506	https://publons.com/a/1559198
Tomislav B. Šekara	control of processes with concentrated and distributed parameters, industrial regulators with optimum performance, fraction laws of control in industrial application, process characterisation, adequate signal discretisation and processing, sensors and actuators, electric energy compensation and saving in electric energy distribution systems	https://orcid.org/0000-0001-8031-3135	https://publons.com/a/1596795
Goran P. Šimić	Inform. systems, computer science, programming, databases, artificial intelligence	https://orcid.org/0000-0002-7563-699X	https://publons.com/a/1600386
Ljubiša K. Tančić	internal ballistics, armaments	https://orcid.org/0000-0003-1242-9333	https://publons.com/a/1623091
Ivan A. Tot	databases, inform.systems, information system security	https://orcid.org/0000-0002-5862-9042	https://publons.com/a/1558155
Slaviša I. Vlačić	air traffic, system control, automatic control, vehicle navigation, naval combat and navigation systems, simulation	https://orcid.org/0000-0001-9336-0512	https://publons.com/a/1604062
Dragoljub A. Vujić	applied mechanics, diagnostics, sofisticated systems for technical system maintenance	https://orcid.org/0000-0001-6999-6828	https://publons.com/a/1627346
Ivan B. Vulić	information systems, geographic information systems	https://orcid.org/0000-0002-5161-5422	https://publons.com/a/1606268

ИЗЈАВА О ЕТИЧКОМ ПОСТУПАЊУ
ЭТИЧЕСКИЙ КОДЕКС
PUBLICATION ETHICS STATEMENT

ИЗЈАВА ВОЈНОТЕХНИЧКОГ ГЛАСНИКА О ЕТИЧКОМ ПОСТУПАЊУ

Објављивање чланака након стручне рецензије основна је делатност научног часописа *Војнотехнички гласник*. Неопходно је постићи сагласност о етичким начелима у поступцима свих учесника приликом објављивања чланака, од аутора, Редакције часописа и стручних рецензената до издавача.

Обавезе Редакције *Војнотехничког гласника*

Уредништво *Војнотехничког гласника* не тражи од аутора плаћање накнаде за аплицирање чланка за објављивање. Читав поступак уређивања и објављивања чланка за ауторе је потпуно бесплатан.

Редакција *Војнотехничког гласника* одговорна је за доношење одлуке који ће од приспелих чланака бити одабран за објављивање. Уредник не сме имати сукоб интереса у вези са рукописима које разматрају. Ако такав сукоб интереса постоји, о избору рецензената и судбини рукописа одлучује уредништво. Чланови уређивачког одбора код којих постоји сукоб интереса дужни су да се повуку из процедуре.

Редакција треба да поступа у складу с политиком Уређивачког одбора *Војнотехничког гласника* као и у складу са законским прописима који се односе на клевету, кршење ауторских права и плагијате. Редакција може да се консултује са члановима Уређивачког одбора или рецензентима при доношењу одлуке.

Редакција процењује садржај рукописа независно од расе, пола, полне оријентације, религијских уверења, етничког порекла, политичких уверења и државне припадности аутора.

У свом раду, према препоруци Центра за евалуацију у образовању и науци (ЦЕОН), Редакција користи електронски систем уређивања АСИСТЕНТ, који омогућава транспарентност и јавност рада, подразумевајући пуну одговорност за прихватање и објављивање чланка.

Пре слања на рецензију Редакција проверава да ли је садржај рукописа плагијат, коришћењем сервиса iThenticate (CrossRef и CrossCheck). Према стандардима које часопис примењује, плагирање, односно преузимање туђих идеја, речи или других облика креативног израза и представљање као својих, представља грубо кршење научне и издавачке етике. Плагирање може да укључује и кршење ауторских права, што је законом кажњиво. Плагијат обухвата: дословно или готово дословно преузимање или смишљено парафразирање (у циљу прикривања плагијата) делова текстова других аутора без јасног указивања на извор или обележавање копираних фрагмената (на пример, коришћењем наводника); копирање слика или табела из туђих радова без правилног навођења извора и/или без дозволе аутора или носилаца ауторских права. Рукописи код којих постоје јасне индиције да се ради о плагијату биће аутоматски одбијени.

Часопис примењује „двоструки слепи поступак рецензије“ чланака, који подразумева да аутори не знају ко су им рецензенти, нити су рецензентима познати аутори.

Нико из уређивачке куће не сме да открије ниједну информацију о пристиглом рукопису икоме, осим аутору, рецензентима, потенцијалним рецензентима, другим саветницима уређивачке куће и издавачу, према потреби.

Необјављен материјал из пристиглих рукописа не сме да се користи за истраживачки рад уређивача, осим са изричитим писменим одобрењем аутора.

Редакција се обавезује да ће повући већ објављени чланак у случају накнадног откривања следећих околности у вези рада:

– плагијаризам,

– аутоплагијаризам,

– рад је већ објављен у другом часопису или некој другој публикацији,

– нетачни подаци о ауторству (присвајање туђег рада, навођење аутора који нису учествовали у писању рада, изостављање аутора који су учествовали у писању рада),

– сукоб интереса,

– лажирање или фабриковање резултата,

– недозвољене техничке интервенције на сликама,

– озбиљнија техничка грешка, као што је изостављање делова текста, грешка у репродукцији илустративног материјала.

Стандарди за разрешавање ситуација када мора доћи до повлачења рада дефинисани су од стране библиотека и научних тела, а иста пракса је усвојена и од стране часописа: у електронској верзији изворног чланка (оног који се повлачи) успоставља се веза (HTML линк) са обавештењем о повлачењу. Повучени чланак се чува у изворној форми, али са воденим жигом на PDF документу, на свакој страници, који указује да је чланак повучен (RETRACTED).

Опозиви и исправке се публикују према захтевима ЦЕОН-а (http://www.ceon.rs/pdf/postupanje_s_nelegitimnim_radovima.pdf) као издавача националног цитатног индекса где се метаподаци опозива и опзваних радова морају означити одговарајућим упозорењима и међусобно повезати унакрсним линковима.

Обавезе рецензената

Рецензенти су дужни да стручно, аргументовано, непристрасно и у задатим роковима доставе уреднику оцену научне вредности рукописа. Рецензенти евалуирају радове у односу на усклађеност теме рада са профилом часописа, релевантност истраживане области и примењених метода, оригиналност и научну релевантност података изнесених у рукопису, стил научног излагања и опремљеност текста научним апаратом.

Стручни рецензент помаже Редакцији у доношењу одлуке, а посредством контаката са ауторима преко Редакције може да помаже и ауторима на побољшавању текста рада.

Уколико изабрани рецензент сматра да није довољно квалификована да изврши рецензију истраживања у рукопису или је пак спречен да заврши и достави рецензију у договореном року, о томе треба благовремено да обавести Редакцију.

Сваки рукопис прихваћен на рецензију мора да се третирати као поверљив документ. Не сме се показивати трећим лицима нити дискутовати са њима, осим када то одобри Редакција.

Рецензија треба да буде објективна. Неприхватљива је лична критика аутора. Рецензенти треба јасно да образложе своје ставове и поткрепе их аргументима.

Рецензенти треба да идентификују релевантне постојеће радове које аутор није цитирао. Свака претходно јавно саопштена тврдња или аргумент треба да буду пропраћени одговарајућим цитатом. Дужност рецензента је да скрене пажњу уреднику на значајна поклапања или сличност рукописа са већ објављеним радом, уколико о томе има лична сазнања.

Информације и идеје до којих се дошло стручном рецензијом поверљивог су карактера и не смеју се користити за сопствене потребе. Рецензенти не би требало

да примају рукописе који их доводе у сукоб интереса на основу конкуренције, заједничког рада или других односа с било којим аутором, компанијом или институцијом повезаним с радом.

Редакција *Војнотехничког гласника* подстиче рецензенте да рецензије верификују на својим персонализованим страницама у бази *Publons*, у складу са упутством на страници сајта: ***Позив и упутство рецензентима за регистрацију у Publons-у*** (http://www.vtg.mod.gov.rs/poziv-i-uputstvo-recenzentima-za-registraciju-u-publons.html). Рецензентска политика часописа, која је верификована у Publons-у:

– омогућава јавно приказивање рецензије (искључиво након објављивања чланка),

– омогућава рецензентима приказивање наслова рецензираног чланка (искључиво након објављивања чланка), у складу са смерницама *Publons*-а.

Обавезе аутора

Аутори гарантују да рукопис представља њихов оригиналан допринос, да није објављен раније и да се не разматра за објављивање на другом месту. Истовремено предавање истог рукописа у више часописа представља кршење етичких стандарда. Такав рукопис се моментално искључује из даљег разматрања.

Када аутори пишу о оригиналном истраживању треба прецизно да прикажу обављени рад и да објективно изложе његов значај. Подаци треба да буду прецизно наведени. Чланак треба да садржи довољно детаља и референци да би могао да се репродукује. Лажне или намерно нетачне тврдње представљају неетичко поступање и неприхватљиве су.

Аутори треба да обезбеде необрађене податке у вези са чланком и пруже их на увид Редакцији, као и јавни приступ тим подацима, ако је то могуће, и да, у сваком случају, буду спремни да сачувају те податке у разумном року после објављивања.

Аутори треба да напишу потпуно оригиналне радове, а ако су користили радове и/или формулације других, онда то треба да наведу на одговарајући начин.

У принципу, аутори би требало да објаве рукопис који се суштински бави истим истраживањем само у једном часопису или примарној публикацији. Слање истог рукописа у више редакција часописа у исто време представља неетичко понашање и неприхватљиво је.

Обавезно је да аутор наведе радове које је користио у писању рукописа, као и да цитира публикације које су утицале на његов рад.

Ауторство треба да буде ограничено на оне који су значајно допринели идеји, њеном обликовању, извођењу или интерпретацији у датом истраживању. Сви који су значајно допринели раду треба да буду наведени као коаутори. Ако су појединци били битни у појединим аспектима истраживачког пројекта, треба им у захвалници одати признање за допринос.

Аутор треба да се постара да сви коаутори буду наведени као такви, као и да међу наведеним нема оних који то не заслужују. Ауторова дужност је да сви коаутори виде и одобре финалну верзију рада, као и да одобре његово објављивање.

Ако се у истраживању појављују хемијска једињења, поступци или опрема који су опасни по здравље људи или животиња, аутор то мора јасно да назначи у рукопису.

Сваки аутор треба да наведе у рукопису све врсте финансијских и осталих значајних конфликата интереса који би могли да утичу на резултате или интерпретацију његовог рада. Сви извори финансијске подршке треба да буду такође наведени.

Када аутор открије материјалну грешку или нетачност у свом објављеном раду, његова је дужност да одмах обавести Редакцију часописа или издавача и да сарађује са Редакцијом при повлачењу или кориговању рада.

Разрешавање спорних ситуација

Сваки појединац или институција могу у било ком тренутку да уреднику и/или уредништву пријаве сазнања о кршењу етичких стандарда и другим неправилностима и да о томе доставе неопходне информације/доказе. Поступак провере изнесених доказа одвијаће се у складу са следећим принципима: уредништво ће донети одлуку о покретању поступка који има за циљ проверу изнесених навода и доказа; током тог поступка сви изнесени докази сматраће се поверљивим материјалом и биће предочени само оним лицима која су директно укључена у поступак; лицима за која се сумња да су прекршила етичке стандарде биће дата могућност да одговоре на оптужбе изнесене против њих; ако се установи да је заиста дошло до неправилности, процениће се да ли их треба окарактерисати ако мањи прекршај или грубо кршење етичких стандарда. Ситуације окарактерисане као мањи прекршај решаваће се у директној комуникацији са лицима која су прекршај учинила, без укључивања трећих лица, нпр.: обавештавањем аутора/рецензената да је дошло до мањег прекршаја који је проистекао из неразумевања или погрешне примене академских стандарда; слањем упозорења аутору/рецензенту који је учинио мањи прекршај. У случају грубог кршења етичких стандарда, уредништво доноси одлуке о даљим акцијама. Мере које ће предузети могу бити следеће (и могу се примењивати појединачно или истовремено): објављивање саопштења или уводника у ком се описује случај кршења етичких стандарда; слање службеног обавештења руководиоцима или послодавцима аутора/рецензента; повлачење објављеног рада у складу са процедуром описаном под Повлачење већ објављених радова; ауторима ће бити забрањено да током одређеног периода шаљу радове у часопис; упознавање релевантних стручних организација или надлежних органа са случајем како би могли да предузму одговарајуће мере. Приликом разрешавања спорних ситуација редакција часописа редакција се руководи смерницама и препорукама Одбора за етику у издаваштву (Committee on Publication Ethics – COPE): http://publicationethics.org/resources/.

Одрицање одговорности

Изнесени ставови у објављеним радовима не изражавају ставове уредника и чланова редакције часописа. Аутори преузимају правну и моралну одговорност за идеје изнесене у својим радовима. Издавач неће сносити никакву одговорност у случају испостављања било каквих захтева за накнаду штете.

Рекламирање

Није дозвољено рекламирање у *Војнотехничком гласнику*.

КОДЕКС ПРОФЕССИОНАЛЬНОЙ ЭТИКИ ЖУРНАЛА *«ВОЕННО-ТЕХНИЧЕСКИЙ ВЕСТНИК»*

Публикация статьей после их профессиональной рецензии является основной деятельностью научного журнала «*Военно-технический вестник*». В первую очередь необходимо достичь договоренности об этических нормах и принципах, применяемых ко всем участникам в процессе выпуска журнала, начиная с автора, Редакционной коллегии, профессиональных рецензентов до издателя.

Обязанности редакторов «***Военно-технического вестника***»

Редакция журнала «*Военно-технический вестник*» сообщает, что не взымает с авторов плату за публикацию их статей, то есть, все действия, связанные с редактированием и размещением статей в Вестнике являются абсолютно бесплатными.

Редакция «*Военно-технического вестника*» несет ответственность за принятие решений о публикации представленных в адрес журнала статей. При наличии конфликта интересов редактор не принимает участия в процессе рассмотрения рукописи. В таком случае решение о выборе рецензента и публикации рукописи принимает редколлегия. При наличии конфликта интересов члены редколлегии не принимают участия в процессе рассмотрения рукописи.

Редакция обязана соблюдать политику Редакционной коллегии «*Военно-технического вестника*», а также положения действующего законодательства, регулирующие вопросы распространения заведомо ложных сведений, порочащих честь и достоинство другого лица или подрывающих его репутацию и несоблюдения авторских прав. Редакция имеет право проконсультироваться с Редакционной коллегией или рецензентами относительно принятия решений о публикации статьи.

Редакция отбирает и оценивает материалы независимо от пола, религии, расы, национальности, политических убеждений автора.

По рекомендациям Центра поддержки развития образования и науки (ЦПРОН), редакция журнала в своей работе пользуется электронной системой редактирования ASSISTANT, обеспечивающей транспарентность и доступность информации о текущем соотоянии рукописи, а также подразумевает полную ответственность за принятие решения о её публикации.

Путём использоваия системы iThenticate (CrossRef и CrossCheck) редакция до момента представления статьи рецензентам проверяет её содержание на плагиат. В соответствии со стандартами журнала, плагиат, то есть присвоение чужих идей, высказываний либо другой формы творческого выражения и представление их как своих собственных представляет собой грубое нарушение научной и редакционной этики. Плагиат является уголовно наказуемым нарушением авторских прав. С точки зрения редакции, плагиатом является: дословное копирование работы другого лица, либо цитирование работы другого лица без указания его авторства, ссылки на источник; некорректное перефразирование произведения другого лица без ссылки на источник; использование элементов работы (рисунков, таблиц, графиков, диаграмм) другого лица без указания авторства, ссылки на источник; авторы должны получить разрешение владельца авторских прав на использование элементов его работы. В случае возникновения обоснованного сомнения в том, что работа является плагиатом, редакция отказывает автору в публикации.

Редакция журнала проводит конфиденциальное рецензирование, применяя «двойной слепой метод». Авторы статьи и рецензенты не знают друг друга.

Никто из работников издательской компании не имеет право раскрывать любые сведения о представленной научной статье, за исключением случаев, если они по

мере потребности нужны автору, рецензентам, возможным рецензентам и другим советникам редакторов и издателя.

Неопубликованными материалами нельзя воспользоваться для исследовательских работ без согласия автора.

Редакция обязуется исключить из публикации принятую статью, в случае следующих нарушений:

– плагиат,

– автоплагиат,

– повторная публикация в данном или другом издании,

– неверные данные об авторе (присвоение чужой работы, указание автора не принимавшего участия в написании работы),

– конфликт интересов,

– фальсификация результатов исследования,

– неправильно оформленные рисунки (графики, иллюстрации) и таблицы,

– крупные технические ошибки в оформлении текста, на-пример, пропуск частей текста.

Стандарты регламентирующие процедуру снятия опубликованной работы с публикации, которые применяет «Военно-технический вестник» предписаны Национальной библиотекой Сербии (НБС) и другими научными учреждениями. За статьей (определённой к снятию) в электронном формате закрепляют HTML ссылку с уведомлением о её снятии с публикации. Изъятая статья хранится в исходном виде, но каждая страница ПДФ формата визируется печатью, свидетельствующей о снятии статьи с публикации (RETRACTED).

Отзывы и исправления публикуются в соответствии с требованиями ЦПРОН – Сербского индекса научного цитирования (СЦИндекс/SCIndex) (http://www.ceon.rs/pdf/postupanje_s_nelegitimnim_radovima.pdf), при этом метаданные отозванных и снятых с публикации статей должны быть обозначены соответствующим предупреждением и соединены между собой ссылками.

Обязанности рецензентов

Рецензенты должны профессионально и объективно аргументировать свою позицию и в указанный срок предоставить редактору оценку научной ценности рукописи.

Рецензенты, рассматривая работы оценивают соответствие темы работы с профилем журнала, релевантность исследуемой области и примененных методов, оригинальность и научную значимость результатов, представленных в рукописи, стиль научного изложения, а также использование в тексте научного аппарата.

Профессиональный рецензент оказывает поддержку Редакции при принятии решений о публикации статьей, а также, оказывает содействие авторам в целях улучшения качества их работы. Взаимодействие рецензента с авторами осуществляется путём контактов с ними через Редакцию.

В случае если рецензент считает, что он в достаточной степени не обладает качествами, необходимыми для осуществления профессиональной рецензии работы, или не сможет её осуществить во время, то ему необходимо об этом проинформировать Редакцию.

Любая работа, представленная на рецензию, является конфиденциальным документом и её нельзя показывать третьим лицам без одобрения Редакции.

Рецензия должна базироваться на объективных условиях. Не допускается личная критика автора. Рецензенты должны обосновать и доказать свои позиции по отношению к статье.

Рецензенты обязаны идентифицировать релевантные существующие работы, которые автор не цитировал. По любому общему сведению или аргументу приведенным в работе должны быть указаны соответствующие цитаты. Рецензент обязан обратить внимание редактору на эвентуальные сходства работы с другими опубликованными работами, в случае если такое будет обнаружено.

Мнение и выводы о рукописи статьи, к которым пришли рецензенты является конфиденциальной информацией и ей нельзя воспользоваться для личных потребностей. Рецензентам рекомендуется не рецензировать работы, которые могут вызвать коллизию интересов (конкуренты, совместная работа, или иные другие отношения с автором, компанией или учреждением связанными с работой).

Редакция журнала «Военно-технический вестник» призывает рецензентов подтверждать свои рецензии на своей личной странице в базе *Publons*, в соответствии с инструкциями, опубликованными на страницах веб-сайта: Приглашение рецензентов и инструкция по регистрации в *Publons* http://www.vtg.mod.gov.rs/priglasenie-recenzentov-i-instrukcija-po-rabote-s-publons.html).

Политика журнала относительно рецензий, которая подтверждена в Publons:

- допускает публичный доступ к рецензии (но только после публикации статьи),
- позволяет рецензентам отображать заголовок рецензируемой статьи (но только после публикации статьи), в соответствии с инструкцией Publons.

Обязанности авторов

В своей исследовательской работе авторы должны придерживаться принципов четкости, разборчивости, понятности с целью объективного растолкования значения данной работы. Факты и показатели должны быть четко указаны. Работа должна содержать в достаточной степени фактов и деталей, чтобы она могла репродуцироваться. Неправильные или неточные утверждения являются примером неэтического поведения и не будут приняты.

Авторы должны обеспечит Редакцию первичными, необработанными данными, относящимися к работе, и представить их на рассмотрение Редакции, и обеспечить к ним доступ всем заинтересованным лицам, если это является возможным. Также, авторы должны после публикации статьи хранить в разумные сроки полученные результаты. Авторы должны в своих работах заниматься полностью оригинальными вопросами. В случае если они в своей работе использовали данные или факты других авторов, то об этом необходимо указать в работе.

Также, авторы должны свои работы публиковать только в одном научном журнале, или размещать публикации на сайте с прямыми ссылками. Публикация одной и той же работы в нескольких научных журналах считается неэтичным поведением и является недопустимой. Авторы работ обязаны указать в своих работах все материалы, которыми они воспользовались при исследовании, в том числе все публикации, которые повлияли на результаты их исследований. Авторство должно быть ограничено только теми лицами, которые в значительной степени участвовали в процессе исследования и получения результатов работы. Имена, отчества, фамилии всех лиц, участвующих в значительной степени в процессе исследования и получения результатов работы, должны быть указаны в работе в качестве соавторов, и их необходимо поблагодарить за содействие.

Автор должен обеспечить условия, чтобы имена, отчества, фамилии всех соавторов, действительно участвующих в процессе исследования и содействующих получению результатов, были указаны в работе. Также, обязанностью автора является предоставление окончательной версии работы соавторам на согласование.

В случае появления в процессе исследования необходимости контакта с опасными веществами, т.е. веществами, обладающими потенциальной опасностью в

отношении человека, животных и окружающей среды, то автор об этом должен четко указать в работе. Каждый автор обязан в работе указать на все виды потенциальных финансовых или других конфликтов интересов, которые могли бы повлиять на результаты исследования или их интерпретацию. Все источники финансовой поддержки должны быть указаны в работе.

В случае обнаружения автором в работе существенные ошибки или какие-либо неточности, он обязан об этом незамедлительно сообщить Редакции журнала или издателю, также оказать содействие в их исправлении.

Разрешение спорных ситуаций

Любое лицо, либо учреждение вправе в любой момент предъявить претензию редактору или редколлегии в связи с нарушением этических стандартов и авторских прав, подкрепив ее достоверными доказательствами.

По получении претензии, подкрепленной доказательствами, редакционная комиссия проведет расследование, в соответствии со следующими принципами: редколлегия принимает решение о проведении проверки по поводу выдвинутых жалоб и доказательств о нарушении редакционной этики; в процессе рассмотрения доказательств, все материалы считаются конфиденциальными и будут предоставлены только тем лицам, которые непосредственно причастны к процессу проверки; подозреваемым лицам в нарушении этических норм будет предоставлена возможность ответить на выдвинутое против них обвинение; в случае выявления нарушения, характеризуется его степень, как грубого или негрубого нарушения этических норм.

В случае негрубого нарушения, редакция напрямую, без содействия третьих лиц, обращается к нарушителю, следующим образом: путем уведомления автора/рецензента о наличии негрубого нарушения, произошедшего вследствие недопонимания, либо несоответственного применения академических стандартов; путем предупреждения автора/рецензента, допустившего негрубое нарушение.

В случае грубого нарушения этических норм, редакция принимает решение о дальнейших мерах. Редакция вправе предпринять следующие меры (одновременно, поочередно или в отдельности): обнародование сообщения, в котором описывается случай нарушения этических стандартов; официальное уведомление руководителей или работодателей автора/рецензента; снятие опубликованной статьи с публикации, в соответствии с предписаниями; авторы-нарушители определенный период времени не будут допускаться к публикации в журнале; уведомление релевантных профессиональных организаций и соответствующих учреждений о случае, в целях привлечения нарушителя к ответственности.

При разрешении спорных ситуаций редакция журнала соблюдает предписания и инструкции Руководства Комитета по этике научных публикаций (Committee on Publication Ethics – COPE): http://publicationethics.org/resources/.

Отказ от ответственности

Вынесенные позиции в опубликованных работах не обязательно отражают точку зрения редколлегии журнала. Авторы несут полную юридическую и моральную ответственность за представленные в своих работах идеи. Редакция не несет никакой ответственности в случае возникновения требований по возмещению материального или морального вреда.

Реклама

Реклама в журнале *«Военно-технический вестник»* не допускается.

PUBLICATION ETHICS STATEMENT

The publication of an article in this peer reviewed journal is an essential model for the scientific journal *Military Technical Courier*. It is necessary to agree upon standards of expected ethical behavior for all parties involved in the act of publishing: the author, the journal editor, the peer reviewer and the publisher.

Duties of the *Military Technical Courier* editor

There are no APCs (author processing charges) or submission charges for the articles submitted to the *Military Technical Courier*. The whole process of article editing and publishing is entirely free of charge for authors.

The editor of the *Military Technical Courier* is responsible for deciding which of the articles submitted to the journal should be published. The Editor must hold no conflict of interest with regard to the articles he/she considers for publication. If an Editor feels that there is likely to be a perception of a conflict of interest in relation to their handling of a submission, the selection of reviewers and all decisions on the paper shall be made by the Editorial Board. If any member of the Editorial Board feels that there is likely to be a perception of a conflict of interest in relation to their handling of a submission, they shall withdraw from the editorial process.

The editor should be guided by the policies of the journal's editorial board and constrained by such legal requirements as shall then be in force regarding libel, copyright infringement and plagiarism. The editor may confer with the members of the editorial board or reviewers in making this decision.

The editor should evaluate manuscripts for their intellectual content without regard to race, gender, sexual orientation, religious belief, ethnic origin, citizenship, or political philosophy of the authors.

Following the recommendations of the CEON Centre for Evaluation in Education and Science (CEON/CEES), the editor applies the electronic editing system ASSISTANT which enables transparency and public access to work and accepts a full responsibility for the acceptance and publishing of articles.

Before sending articles for peer reviews, the editor checks the content of the submitted manuscripts for plagiarism using the iThenticate service (CrossRef and CrossCheck). According to the standards applied by the journal, plagiarism, where someone assumes another's ideas, words, or other creative expression as one's own, is a clear violation of scientific ethics. Plagiarism may also involve a violation of copyright law, punishable by legal action. Plagiarism includes the following: word for word, or almost word for word copying, or purposely paraphrasing portions of another author's work without clearly indicating the source or marking the copied fragment (for example, using quotation marks); copying equations, figures or tables from someone else's paper without properly citing the source and/or without permission from the original author or the copyright holder. Any manuscript which shows obvious signs of plagiarism will be automatically rejected.

Journal applies a „double blind peer review process“ for papers. Authors and reviewers are anonymous to each other in the process of review.

The editor and any editorial staff must not disclose any information about a submitted manuscript to anyone other than the corresponding author, reviewers, potential reviewers, other editorial advisers, and the publisher, as appropriate.

Unpublished materials disclosed in a submitted manuscript must not be used in an editor's own research without the express written consent of the author.

The Editorial Office has pledged to remove an already published article in case of the following, subsequently discovered facts regarding the article in question:

– plagiarism,

– self-plagiarism,
– article already published in some other journal or publication,
– inaccurate data on authorship (fake claim of authorship, listing authors who did not participate in the article's creation or omitting authors who did participate),
– conflict of interests,
– fraudulent use of data or fabrication of results,
– unauthorised technical interventions on figures,
– substantial technical error such as omitting parts of the text or an error in reproducing illustrations.

Standards for dealing with retractions have been developed by a number of library and scholarly bodies, and this practice has been adopted for article retraction by our journal: in the electronic version of the retraction note, a link is made to the original article. In the electronic version of the original article, a link is made to the retraction note where it is clearly stated that the article has been retracted. The original article is retained unchanged, save for a watermark on the PDF indicating on each page that it is "RETRACTED".

Retractions and corrections are published according to the requirements set up by CEON/CEES (http://www.ceon.rs/pdf/postupanje_s_nelegitimnim_radovima.pdf) as the publisher of national citation index, where metadata of retractions and retracted papers have to be marked by appropriate warnings and cross-links.

Duties of reviewers

Reviewers are required to provide written, competent and unbiased feedback in a timely manner on the scholarly merits and the scientific value of the manuscript.

The reviewers assess manuscript for the compliance with the profile of the journal, the relevance of the investigated topic and applied methods, the originality and scientific relevance of information presented in the manuscript, the presentation style and scholarly apparatus.

A peer reviewer assists the editor in making editorial decisions and through the editorial communications with the author may also assist the author in improving the paper.

Any selected referee who feels unqualified to review the research reported in a manuscript or knows that its prompt review will be impossible should notify the editor and excuse himself from the review process.

Any manuscripts received for review must be treated as confidential documents. They must not be shown to or discussed with others except as authorized by the editor.

Reviews should be conducted objectively. Personal criticism of the author is inappropriate. Referees should express their views clearly with supporting arguments.

Reviewers should identify relevant published work that has not been cited by the authors. Any statement that an observation, derivation, or argument had been previously reported should be accompanied by the relevant citation. A reviewer should also call to the editor's attention any substantial similarity or overlap between the manuscript under consideration and any other published paper of which they have personal knowledge.

Unpublished materials disclosed in a submitted manuscript must not be used in a reviewer's own research without the express written consent of the author. Privileged information or ideas obtained through peer review must be kept confidential and not used for personal advantage. Reviewers should not consider manuscripts in which they have conflicts of interest resulting from competitive, collaborative, or other relationships or connections with any of the authors, companies, or institutions connected to the papers.

The Editorial Team of the *Military Technical Courier* encourages the reviewers to verify their reviews in their personal profile on *Publons* in accordance with the instructions on the website page: Call and instructions to reviewers for the registration in *Publons*

(http://www.vtg.mod.gov.rs/call-and-instructions-to-reviewers-for-the-registration-in-publons.html).

The reviewing policy of the Journal, verified in Publons:

- allows public display of the review (only after the article has been published),
- allows reviewers to display the title of the reviewed article (only after the article has been published), in accordance with the guidelines of Publons.

Duties of authors

Authors warrant that their manuscript is their original work, that it has not been published before and is not under consideration for publication elsewhere. Parallel submission of the same paper to another journal constitutes a misconduct and eliminates the manuscript from consideration by the journal.

The reviewers assess manuscript for the compliance with the profile of the journal, the relevance of the investigated topic and applied methods, the originality and scientific relevance of information presented in the manuscript, the presentation style and scholarly apparatus.

Authors of reports of original research should present an accurate account of the work performed as well as an objective discussion of its significance. Underlying data should be represented accurately in the paper. A paper should contain sufficient detail and references to permit others to replicate the work. Fraudulent or knowingly inaccurate statements constitute unethical behavior and are unacceptable.

Authors may be asked to provide the raw data in connection with a paper for editorial review, and should be prepared to provide public access to such data if practicable, and should in any event be prepared to retain such data for a reasonable time after publication.

The authors should ensure that they have written entirely original works, and if the authors have used the work and/or words of others, that this has been appropriately cited or quoted.

An author should not in general publish manuscripts describing essentially the same research in more than one journal or primary publication. Submitting the same manuscript to more than one journal concurrently constitutes unethical publishing behavior and is unacceptable.

Proper acknowledgment of the work of others must always be given. Authors should cite publications that have been influential in determining the nature of the reported work.

Authorship should be limited to those who have made a significant contribution to the conception, design, execution, or interpretation of the reported study. All those who have made significant contributions should be listed as co-authors. Where there are others who have participated in certain substantive aspects of the research project, they should be acknowledged or listed as contributors.

The corresponding author should ensure that all appropriate co-authors and no inappropriate co-authors are included on the paper, and that all co-authors have seen and approved the final version of the paper and have agreed to its submission for publication.

If the work involves chemicals, procedures or equipment that have any unusual hazards inherent in their use, the author must clearly identify these in the manuscript.

All authors should disclose in their manuscript any financial or other substantive conflict of interest that might be construed to influence the results or interpretation of their manuscript. All sources of financial support for the project should be disclosed.

When an author discovers a significant error or inaccuracy in his/her own published work, it is the author’s obligation to promptly notify the journal editor or publisher and cooperate with the editor to retract or correct the paper.

Procedures for dealing with unethical behaviour

Anyone may inform the editors and/or Editorial Staff at any time of suspected unethical behaviour or any type of misconduct by giving the necessary information/evidence to start an investigation. The investigation shall conform to the following principles: the Editorial Staff will initiate an investigation; during an investigation, any evidence should be treated as strictly confidential and only made available to those strictly involved in investigating; the accused will always be given the chance to respond to any charges made against them; if it is judged at the end of the investigation that misconduct has occurred, then it will be classified as either minor or serious/major. Minor misconduct will be dealt directly with those involved without involving any other parties, e.g.: communicating to authors/reviewers whenever a minor issue involving misunderstanding or misapplication of academic standards has occurred, or a warning letter to an author or reviewer regarding fairly minor misconduct. In case of major misconduct, the Editorial Staff should make decisions regarding the course of action to be taken using the evidence available. The possible outcomes are as follows (these can be used separately or jointly): publication of a formal announcement or editorial describing the misconduct; informing the author's (or reviewer's) head of department or employer of any misconduct by means of a formal letter, the formal, announced retraction of publications from the journal in accordance with the Retraction Policy (see below); a ban on submissions from an individual for a defined period; referring a case to a professional organization or legal authority for further investigation and action. When dealing with unethical behaviour, the Editorial Staff will rely on the guidelines and recommendations provided by the Committee on Publication Ethics (COPE): http://publicationethics.org/resources/.)

Disclaimer

The views expressed in the published works do not express the views of the Editors and Editorial Staff. The authors take legal and moral responsibility for the ideas expressed in the articles. Publisher shall have no liability in the event of issuance of any claims for damages. The Publisher will not be held legally responsible should there be any claims for compensation.

Advertising

Advertising in the *Military Technical Courier* is not permitted.

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
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

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
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

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
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

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


ОД 1953.
ВТГ
ГОДИНА


OD 1953.
VTG
GODINA


С 1953 г.
ВТБ
ЛЕТ


SINCE 1953
MTG
YEARS