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Adrian-Iulian BREZULIANU

1. A. Brezulianu, O.Geman, IV Popa (2023), Artificial Intelligence Component of the Ferodata AI Engine to Optimize the Assignment of Rail Freight Locomotive Drivers, Applied Sciences 13 (20), 11516, https://www.mdpi.com/2076-3417/13/20/11516, (impact factor 2,7)

2. Munisamy Shyamala Devi, Venkatesan Dhilip Kumar, Adrian Brezulianu, Oana Geman, Muhammad Arif (2023) "A Novel Blunge Calibration Intelligent Feature Classification Model for the Prediction of Hypothyroid Disease", https://www.mdpi.com/1424-8220/23/3/1128, Sensors 23 (3), 1128, https://www.mdpi.com/1424-8220/23/3/1128 (impact factor 3,9)

3. Brezulianu A, Burlacu A, Popa IV, Arif M and Geman O (2022) "Not by Our Feeling, But by Other's Seeing": Sentiment Analysis Technique in Cardiology—An Exploratory Review. Front. Public Health 10:880207. doi: 10.3389/fpubh.2022.880207, https://www.frontiersin.org/articles/10.3389/fpubh.2022.880207/full (impact factor: 5.2)

4. A Burlacu, C Brinza, A Brezulianu, A Covic, "Accurate and early detection of sleepiness, fatigue and stress levels in drivers through heart rate variability parameters: a systematic review", Reviews in cardiovascular medicine, vol. 22, 3, pp. 845-852, 2021, http://venus-pro-bucket.s3.amazonaws.com/journal/RCM/22/3/10.31083/j.rcm2203090/2153-8174-22-3-845.pdf (impact factor: 4.43)

5. Sebastian Balos, Daniel Howard, Adrian Brezulianu, Danka Labus Zlatanovi, "Perforated Plate for Ballistic Protection—A Review", Metals 2021, 11(4), 526, https://doi.org/10.3390/met11040526 (impact factor: 2,695) https://www.mdpi.com/journal/metals

6. A. Brezulianu, O. Geman, M. Arif, I. Chiuchisan, O. Postolache, "Epidemiologic evolution platform using integrated modeling and geographic information system," Computers, Materials & Continua, vol. 67, no.2, pp. 1645–1663, 2021, https://www.techscience.com/cmc/v67n2/41317 (impact factor: 3,86) https://www.techscience.com/journal/cmc

7. Brezulianu, A.; Geman, O.; Zbancioc, M.D.; Hagan, M.; Aghion, C.; Hemanth, D.J.; Son, L.H. IoT Based Heart Activity Monitoring Using Inductive Sensors, Sensors 2019, 19, 3284, https://www.mdpi.com/1424-8220/19/15/3284, https://www.mdpi.com/journal/sensors/imprint (impact factor: 3,30)

8. Adrian Brezulianu; Cristian Aghion; Marius Hagan; Oana Geman; Iuliana Chiuchisan; Alexandra Balan; Doru Balan; Valentina Emilia Balas, Active Control Parameters Monitoring for Freight Trains, using Wireless Sensor Network Platform and Internet of Things, Processes, 2020, 8(6), 639, https://doi.org/10.3390/pr8060639, https://www.mdpi.com/journal/processes (impact factor: 3,5)

9. Daniel Howard, Adrian Brezulianu, Joseph Kolibal - Genetic Programming of the Stochastic Interpolation Framework: Convection Diffusion Equation, Soft Computing, Springer, ISSN 1432-7643, (impact factor: 1,271)

10. Daniel Howard, Adrian Brezulianu, Homology, Analogy and Cybernetics Ideas could help the counter terrorism effort, Romanian Intelligence Studies Review, no.11/June 2014, pp.25-32, ISSN 2067-3353.

Reviews in Cardiovascular Medicine

Systematic Review

Accurate and early detection of sleepiness, fatigue and stress levels in drivers through Heart Rate Variability parameters: a systematic review

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Sleepiness, fatigue, and stress in drivers are the leading causes of car crashes. In the late two decades, there is an endeavor to monitor vital signs, stress levels, and fatigue using adapted sensors supported by technological advances. To the best of our knowledge, this systematic review is the first to investigate the role of HRV measurement for sleepiness, fatigue, and stress level monitoring in car drivers. A search was performed in PubMed, Embase, and Cochrane databases using prespecified keywords. Studies were considered for inclusion if they reported original data regarding the association between different HRV measurements and drivers' sleepiness, fatigue, or stress levels. Of the retrieved 749 citations, 19 studies were finally included. The sensibility and specificity of HRV significantly varied across studies, respectively 47.1%–95% and 74.6%–98%. Accuracy was also different, ranging from 56.6% to 95%. Nevertheless, in real-world conditions, confounding factors could affect sympathovagal tone and HRV. Multiple HRV parameters measurement rather than one parameter approach seems to be the optimal strategy for evaluating the vigilance state in drivers that it would be possible to achieve a good performance. As all studies were observational, data should be confirmed in randomized controlled trials. In conclusion, HRV represents a potentially valuable marker for sleepiness, fatigue, and stress monitoring in car drivers. HRV measurements could be implemented in future clinical models and sensors to detect early sleepiness and fatigue and prevent car crashes. More studies with larger populations are needed to support this evidence.

Keywords

Heart rate variability; Drivers; Fatigue; Sleepiness; Stress detection; Systematic review

1. Introduction

Heart rate variability (HRV) defines the changes in the time interval of cardiac sinus node depolarization, thus reflecting a balance between sympathetic and parasympathetic nervous systems activity [1]. It seems that HRV is impacted by stress, current neurobiological evidence supporting its use for the objective assessment of psychological health, stress, and fatigue [2].

Neglected since the last guidelines published in 1996 by The Task Force of The European Society of Cardiology (ESC) and The North American Society of Pacing and Electrophysiology, HRV represents a reliable marker of cardiac function [3]. In the last decade, researchers revisited the idea of HRV measurement, as it could help to monitor vital signs, stress levels, and fatigue using adapted sensors, which are supported by technological progress. Moreover, it seems that HRV could have important clinical implications in various pathological conditions involving the heart, the brain, or the kidney [4, 5].

Although HRV measurement was adopted for sinus rhythm, there is increasing evidence of its usefulness in patients with atrial fibrillation for both detection and risk stratifying. The authors developed an algorithm for atrial fibrillation detection based on HRV measurements and atrial activity in one study. The results were impressive, as the proposed model had 98% sensitivity and 97.4% specificity [6]. Moreover, the HRV index was associated with a greater risk of cardiovascular death ($p = 0.01$) and all-cause death ($p = 0.01$) [7]. Besides cardiovascular implications, some HRV parameters could also be associated with mortality in patients with chronic kidney disease [8].

HRV could be measured using different parameters derived from time-domain methods, frequency-domain methods, and non-linear methods analysis. Time-domain methods represent the easiest way to assess HRV, expressed as fluctuations in heart rate and cycle length. Most parame-

ters acquired from the time-domain analysis are based on normal-to-normal (NN) intervals, representing the intervals between consecutive QRS complexes [3, 9]. From the available time-derived parameters, four were recommended for evaluation by the Guidelines: standard deviation of all NN intervals (SDNN), the standard deviation of the average NN interval over short time divisions (SDANN), the square root of the mean squared differences of consecutive NN intervals (RMSSD) and HRV triangular index.

Usually, SDNN and HRV triangular index are used to appraise overall HRV [3]. Frequency-domain measurements imply an analysis of individual spectral components of HRV, ultra-low frequency (ULF), very low frequency (VLF), low frequency (LF), high frequency (HF). Subsequently, the power of each frequency band is calculated. Importantly, HRV using frequency-domain methods could be analyzed over short- or long-time intervals (2 minutes–24 hours) [3, 9]. However, variations in HRV are not linear, highlighting the complexity of modulation systems. The most used non-linear parameters for HRV assessment are represented by approximate entropy, sample entropy, S, SD1, SD2, and detrended fluctuation analysis [9].

Available data suggest that increased parasympathetic nervous system activity is associated with increased HRV. However, a plateau level could exist, beyond which a further increase in parasympathetic activity did not induce a higher HRV [10]. HF is associated with vagal activity regarding frequency-domain parameters, while LF is considered a marker of sympathetic activity. However, few studies suggested that LF might be reflecting both components of the autonomic nervous system. In addition, HRV response to autonomic nervous system modulation could be susceptible to high inter-individual variations [3]. Besides the physiological modulation of heart rate and, subsequently, of HRV, the correlation between HRV and heart rate could be described as a mathematical model of a non-linear inverse relationship [11].

Clinical studies consistently documented that HRV parameters are used in psychomotor vigilance evaluation, sleepiness, and fatigue detection [12–14]. Notably, HRV assessment, especially as frequency-domain, could detect sleepiness early, within minutes before falling asleep [15]. Thus, a practical application of HRV measurements could consist of activity state evaluation in drivers since sleepiness, fatigue, and drivers' stress are the leading causes of car crashes [16, 17]. Some reviews in the literature investigated different approaches for sleepiness and fatigue detection in drivers; however, the authors focused on a variety of physiological signs, and the importance of HRV monitoring was only partly explored [18–20].

We aimed to systematically review the literature to investigate the importance of HRV assessment (expressed as time-domain measures, frequency-domain measures, or non-linear analysis) for sleepiness, fatigue, and stress level monitoring in drivers.

2. Materials and methods

We conducted the present systematic review according to the updated Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) [21].

2.1 Data sources and search strategy

A literature search was performed from inception to June 15, 2021, in the following databases: MEDLINE (PubMed), Embase, and Cochrane. No time interval filter was applied. We also screened the cited articles and Google Scholar references, and a database of clinical trials (ClinicalTrials.gov) to find additional studies. According to the PRISMA search checklist, we included full search strategies for prespecified databases in **Supplementary Table 1**. In addition, we restricted the search to studies involving humans. In the search process, the following MeSH terms and keywords were used: "heart rate variability", "sleepiness", "drivers", "accidents", "mental fatigue" and "stress".

2.2 Eligibility criteria and outcomes

Several inclusion criteria were prespecified: (1) studies involving adult humans aged $\geq$18 years; (2) studies reporting original data regarding the outcome of interest, namely the association between different HRV parameters and drivers' sleepiness, fatigue, or stress levels; (3) studies which evaluated drivers' outcomes during real-road or driving-simulator conditions; (4) studies which measured standard HRV parameters stated in guidelines [3]. In addition, studies available only in abstract, letters, editorials, meta-analyses, unpublished data, overlapping population, and those from which we could not extract data were excluded. Two independent investigators evaluated the inclusion and exclusion criteria for each study considered for inclusion. Disagreements were solved by consensus.

2.3 Data collection

In line with PRISMA recommendations, two independent investigators extracted the following data from each included study in the present systematic review: first author, year of publication, number of participants enrolled, age, investigated HRV parameters, setting, and reported results. We presented data as numbers, percentages, ranges of variation, median or mean values, confidence intervals, and *p*-values when available. If disagreements appeared, they were solved by consensus.

2.4 Quality assessment

We appraised the quality of included observational studies using a National Institutes of Health (NIH) tool designed for studies without a control arm [22]. Briefly, this tool encompasses 14 signaling questions which help in evaluating the overall study quality.

3. Results

Our endeavor in the prespecified databases retrieved 749 citations. After excluding duplicate references and citations based on title or abstract evaluation, 62 studies were left for

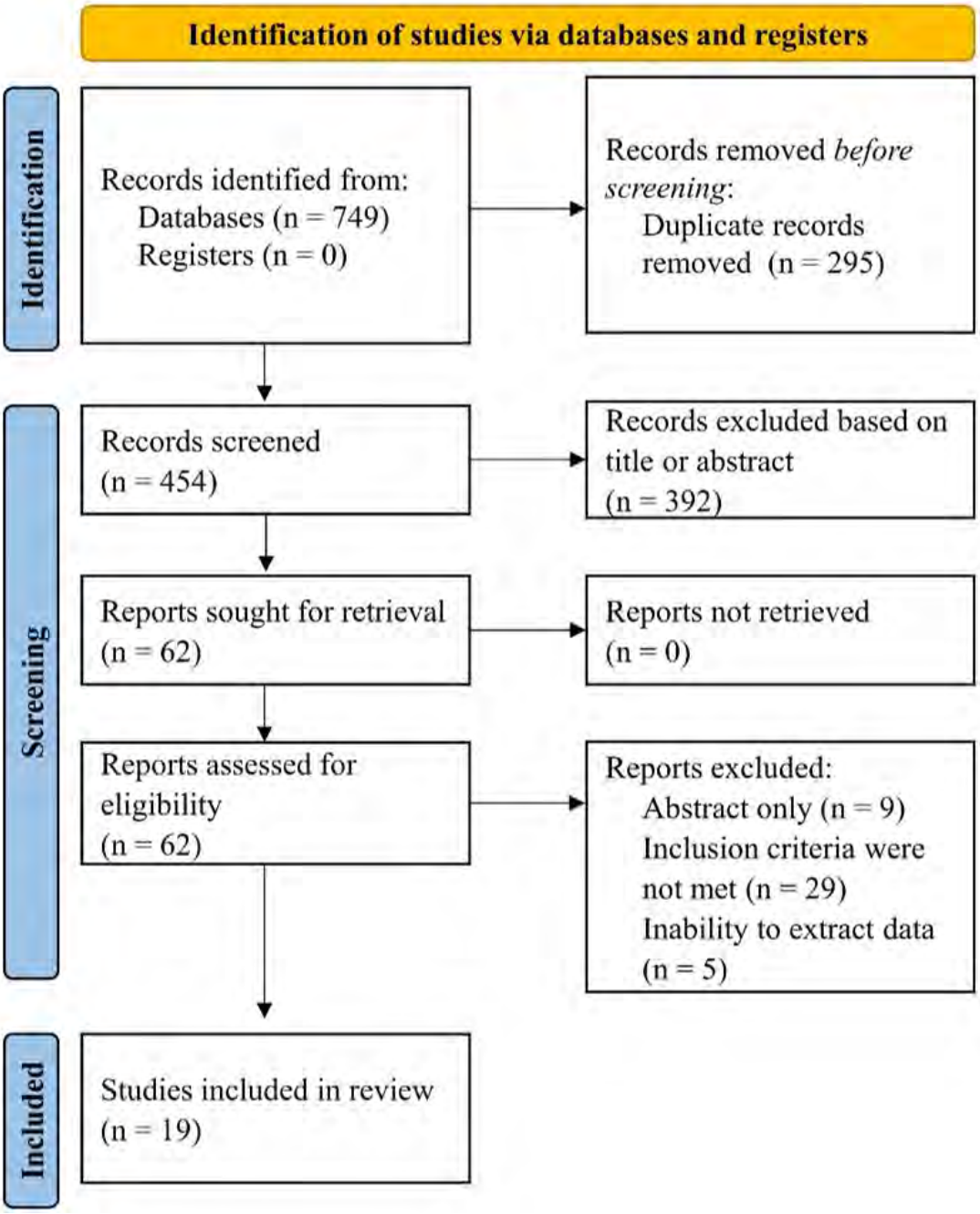

Fig. 1. Flow diagram of selected studies in present systematic review. Our search in MEDLINE, Embase and Cochrane databases retrieved 749 references, from which 19 studies were included in this review after exclusion of citations based on title and abstract, duplicate references and those which did not meet the inclusion criteria.

eligibility assessment. Of the screened studies, 19 met the inclusion criteria and were included in our systematic review. The search and screening process were reported in Fig. 1.

All included studies had an observational, non-randomized design [15, 23–40]. Data regarding participants enrolled in each study, investigated HRV parameters, clinical setting, and major findings were reported in Table 1 (Ref. [15, 23–40]). The most of studies investigated the value of HRV measurements for sleepiness or drowsiness detection in drivers [15, 23–27, 29–31, 33, 34, 37, 39, 40], followed by stress [28, 35, 38] and fatigue [32, 36] detection. In addition, seven studies included drivers on real-roads [23, 24, 28, 33–35, 40], while the rest performed experiments on driving simulators. The quality of included studies in the present systematic review was low, given that all studies were observational and non-randomized, with a small number of participants included (**Supplementary Table 2**).

Table 1. General characteristics of studies included in the present systematic review.

Study, year	Patients, No	Age, median/mean ± SD/range	Investigated parameters	Clinical setting	Findings
Abtahi, 2017 [23]	10	38 ± 9	Time-domain measures and frequency-domain measures	Drivers' sleepiness on real roads (Karolinska Sleepiness Scale)	HRV measures could have potential use in sleepiness detection (individualized approach) Statistically significant for severe sleepiness at 0.05 level: - SDNN 53.2 ± 23, 95% CI (48.0–58.4) - SDANN 37.4 ± 16, 95% CI (33.7–41.0) - SDNNi 377.8 ± 52, 95% CI (366.2–389.4) - NN50 52.8 ± 48, 95% CI (42.1–63.4) - LF 449.5 ± 365, 95% CI (368.3–530.8) - HF 241.2 ± 212, 95% CI (194.1–288.3) - TP 741.4 ± 584, 95% CI (611.5–871.4)
Buendia *et al.*, 2019 [24]	76	44.8 ± 7.8 (study 1) 45 ± 8.2 (study 2) 35.4 ± 9.6 (study 3)	Time-domain measures and frequency-domain measures	Drivers' sleepiness on a public motorway (Karolinska Sleepiness Scale)	HRV measures were associated with perceived sleepiness, irrespective of pre-processing methods Most HRV indices could distinguish between sleepy and alert drivers
Fujiwara *et al.*, 2019 [25]	34	22.7	Time-domain measures and frequency-domain measures	Drivers' drowsiness in comparison with electroencephalography data for sleep scoring (simulator—virtual vehicle)	The developed algorithm based on HRV indices identified 12 of 13 pre-N1 episodes (electroencephalography data), with a false positive rate of 1.7 times per hour
Li *et al.*, 2013 [26]	4	26–33	LF/HF ratio vs wavelet transform method	Drivers' drowsiness detection (Karolinska Sleepiness Scale)	The wavelet method performed better than conventional LF/HF ratio: 95% accuracy (vs 68.8%), 95% sensitivity (vs 62.5%), 95% specificity (vs 75%)
Hendra *et al.*, 2019 [27]	4	22	Time-domain measures and frequency-domain measures (LF and HF)	Drivers' drowsiness detection based on HRV measures and radial basis functional neural network (driving simulator)	The developed model showed a 79.26% accuracy in drowsiness detection (30 s segmentation in RR interval)
Lee *et al.*, 2007 [28]	1	24	Time-domain measures	Drivers' stress detection in a laboratory and on real roads	Heart rate was increased in a stressful driving situation, but SDNN, RMSSD, and pNN50 parameters were decreased At night driving, heart rate was lower, but SDNN, RMSSD, and pNN50 were higher
Mahachandra *et al.*, 2012 [29]	16	42.5 ± 11.52	Time-domain measures, frequency-domain and non-linear measures	Drivers' sleepiness detection using a driving simulator (Karolinska Sleepiness Scale)	RMSSD performed better than other parameters in drivers' sleepiness detection A 28% decline of RMSSD is a valid and sensitive parameter for sleepiness detection
Michail *et al.*, 2008 [30]	21	26.5	Time-domain measures and frequency-domain measures	Drivers' sleepiness and loss of control detection using a driving simulator	Lower values of LF and a lower LF/HF ratio were associated with sleepiness, hypovigilance state, and occurrence of driving errors
Murata *et al.*, 2008 [31]	5	21–26	Time-domain measures	Drivers' drowsiness detection based on HRV measures and electroencephalography data (in a laboratory)	HRV measures (RRV3) increased in the case of drowsy participants in concordance with electroencephalography data

Table 1. Continued.

Study, year	Patients, No	Age, median/mean ± SD/range	Investigated parameters	Clinical setting	Findings
Patel *et al.*, 2011 [32]	12	47 ± 11	Time-domain measures and frequency-domain measures	Early detection of drivers' fatigue based on HRV measures and neural network analysis (driving simulator)	The neural network based on HRV measures showed 90% accuracy in fatigue detection A lower LF/HF ratio was reported (1.2 ± 0.9) in comparison to the alert state (1.7 ± 1.1), $p = 0.01$
Persson *et al.*, 2019 [33]	18 (first experiment) 24 (second experiment) 44 (third experiment)	41 (first experiment) 35 (second experiment) 44 (third experiment)	Time-domain measures and frequency-domain measures	Drivers' sleepiness in real road driving conditions (Karolinska Sleepiness Scale)	Mean accuracy 56.0 ± 1.5 (53.5–57.9) Mean sensitivity 47.1 ± 3.0 (43.3–52.2) Mean specificity 74.6 ± 1.5 (72.6–76.5) Confounding factors in the real world could modulate HRV measures
Vicente *et al.*, 2016 [34]	30	25–60	Time-domain measures and frequency-domain measures	Drivers' drowsiness detection on a driving simulator and real roads	Drowsiness detection based on HRV measures: positive predictive value 0.96, sensitivity 0.59, specificity 0.98 Sleep-deprivation state based on HRV measures: positive predictive value 0.80, sensitivity 0.62, specificity 0.88 HRV could improve car safety mechanisms
Yu *et al.*, 2016 [35]	10	20–65	Time-domain measures and frequency-domain measures	Drivers' stress evaluation on-road driving experiments	HRV based on three parameters: mean RR, SDNN, and HRV triangular index were associated with drivers' stress level Frequency-domain measures were not associated with stress levels
Zhao *et al.*, 2012 [36]	13		Time-domain measures and frequency-domain measures	Drivers' mental fatigue on a driving simulator	At the end of the driving task, LF increased (from 732.7 to 1057.5, $p = 0.009$), but HF decreased (from 859.03 to 626.18, $p = 0.039$), suggesting that sympathetic activity is predominant after the task
Abe *et al.*, 2016 [37]	27	20–49	Time-domain measures and frequency-domain measures	Drivers' drowsiness detection on a driving simulator	The developed model showed a 68% average sensitivity in drowsiness detection Drowsiness was detected in 7 out of 8 participants based on HRV measurements and multivariate statistical process control
Li *et al.*, 2002 [38]	8	24.87	Frequency-domain measures (TP, LF, HF, LF/HF).	Drivers' mental stress and workload (experimental vigilance task) on a driving simulator	After performing the vigilance task, LF increased ($p < 0.05$), LF/HF ratio was higher, and HF decreased ($p < 0.01$)
Awais *et al.*, 2017 [39]	22	18–35	Frequency-domain measures (VLF, LF, HF, LF/HF)	Drivers' drowsiness detection on a driving simulator	VLF, LF, HF, and LF/HF were different between alert and drowsy drivers ($p < 0.05$) HRV parameters accuracy = 70% EEG combined with HRV accuracy = 80.9%
Rodriguez-Ibanez *et al*, 2012 [40]	10	41 ± 9	Time-domain measures and frequency-domain measures	Professional drivers' drowsiness detection on real highway roads	Alert vs drowsy states: - SDNN 63.6 ± 21.1 vs 73.7 ± 24.3 ($p < 0.005$) - LF/HF 3.18 ± 1.58 vs 4.33 ± 2.27 ($p < 0.05$)
Furman *et al.*, 2008 [15]	10	22–40	Time-domain and frequency-domain measures (VLF, LF, HF, LF/HF)	Early sleepiness detection on a driving simulator	VLF decreased consistently within 5 minutes before falling asleep HF increased within seconds before falling asleep LF/HF decreased within minutes before falling asleep

HF, power in high-frequency range; LF, power in low-frequency range; NN50, number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording; pNN50, NN50 count divided by the total number of all NN intervals; RMSSD, the square root of the mean of the sum of the squares of differences between adjacent NN intervals; SDANN, standard deviation of the averages of NN intervals in all 5 min segments of the entire recording; SDNN, standard deviation of all NN intervals; SDNNi, mean of the standard deviations of all NN intervals for all 5 min segments of the entire recording; TP, total power; VLF, power in a very-low-frequency range.

Sensitivity and specificity of HRV for sleepiness and fatigue detection varied across studies, respectively from 47.1% [33] to 95% [26] and from 74.6% [33] to 98% [34]. Accuracy reported in studies was also different, ranging from 56.6% [33] to 95% [26]. Potential confounding factors could partly explain these discrepancies in real-road driving situations, which might influence the balance between parasympathetic and sympathetic activities and, subsequently, HRV measurements.

Overall, results reported in studies included in the present systematic review were consistent across studies. Sleepiness and drowsiness were associated with higher HRV, while drivers in alert states exhibited lower HRV but increased heart rate. Regarding frequency-domain measurements, drowsy drivers had higher HF power and reduced LF/HF ratio, reflecting an increased parasympathetic activity. However, in one study, the authors observed somewhat different results [40]. HRV time-domain parameter, SDNN, was increased in drowsy drivers ($p < 0.005$), which is in line with other studies, but LF/HF ratio was also higher ($p < 0.05$). However, results are limited by the small number of participants enrolled (n = 10) in the analysis, who were professional drivers with a potential different HRV response. Moreover, sympathetic activity might be emphasized in real driving situations due to the stress of avoiding an accident [24].

One study evaluated the importance of HRV for drowsiness detection and compared it with electroencephalography (EEG) data [25]. The developed HRV-based algorithm detected 12 out of 13 pre-N1 episodes (transitional sleep), suggesting that HRV could be a valuable parameter for drowsy state monitoring in drivers. Similar and concordant results between HRV and EEG recordings were reported in another study [31]. Moreover, to achieve better accuracy for sleepiness detection, HRV measurements could be combined with EEG data recorded using an additional electrode. In one study, authors proposed a model which included EEG and HRV data, with 80.9% accuracy [39].

Notably, the authors from one study [32] developed HRV based model using artificial intelligence (neural network analysis) and observed an excellent accuracy for fatigue detection (90%). Also, LF/HF ratio decreased to 1.2 ± 0.87 in the fatigue state from 1.8 ± 1.15 in the alert state, denoting the parasympathetic activity. Another neural network algorithm was developed for drowsiness detection in drivers, with a 79.26% accuracy [27].

HRV parameters appeared to help fall asleep detection within several minutes before the event occurrence [15]. Power decrease in VLF band preceded falling asleep event in drivers with 5 minutes. LF/HF ratio also showed a decreased value within minutes previous to falling asleep. Although this evidence suggests that HRV could represent an early and valuable marker of sleepiness detection, results are limited by the small number of drivers enrolled (n = 10) and should be confirmed in more extensive trials.

Concerning stress evaluation in drivers, three studies [28, 35, 38] revealed that HRV measured by time methods was lower in stressful driving situations. However, data on frequency-domain measures were discrepant. One study concluded that frequency-domain parameters were not associated with stress levels in drivers [35], while another study observed an increased LF and a higher LF/HF ratio [38].

4. Discussions

To the best of our knowledge, this systematic review is the first to investigate the role of HRV measurement for sleepiness, fatigue, and stress level monitoring in car drivers. Currently, fatigue detection systems for drivers are based on algorithms that involve monitoring steering movements patterns (e.g., Bosch [41]) or detecting eye/pupil movements [42, 43].

Recently, HRV monitoring gained interest, as it appears to be a reliable marker of worse outcomes in various pathological conditions. One meta-analysis which involved patients without cardiovascular disease revealed that a reduced HRV was associated with a greater risk of first adverse cardiovascular events, up to 45% [44]. Also, HRV measured as both time- and frequency-domains was associated with cardiovascular risk in another study [45]. Moreover, patients with heart failure or myocardial infarction and a decreased HRV exhibited a higher mortality risk [46].

As HRV parameters were linked to psychomotor vigilance in clinical studies [12, 13], drivers seem to be an appropriate population to benefit from HRV monitoring. Newly developed wireless sensors supported this for vital signs assessment which allows remote control data collection and interpretation. One study proposed a device that used a photoplethysmographic signal with a good performance reported in measuring both time- and frequency-domain parameters [47]. A complex system was recently described, which used artificial intelligence to achieve a reasonable measure performance and integrate most parameters, including time- and frequency methods and non-linear data. Moreover, feedback data are collected in order to achieve optimal function [48]. These data support integrating HRV parameters in future car devices based on artificial intelligence to improve traffic safety.

Notably, there are different wearable devices capable of HRV monitoring, like Bitt Faros, Bodyguard 2, Actiheart, and others [49]. These hardware and software features could represent the first steps for integrating HRV monitoring in cars, as it is required a device with reduced dimensions but with optimal performance, which would not affect the driving process. In this regard, a system was described for HRV measurement from the steering wheel, which displayed similar results with electrocardiography data [50].

Multiple HRV parameters measurement rather than one parameter approach seems to be the optimal strategy for evaluating the vigilance state in drivers that it would be possible to achieve a good performance. Using also frequency-domain parameters could help to create patterns of sleepy or stressed drivers. As reported in the studies included in the present systematic review, sleepiness was usually associated with high

HF power and decreased LF power, while stress driving situations were associated with increased LF power and reduced and low HF power [23, 26]. However, HRV could be susceptible to variations due to external factors related to real-roads driving, like social stress, noise, and CO levels [51]. In this case, non-linear parameters, in addition to the others, might help to distinguish between different clinical states and to create specific patterns.

Moreover, HRV parameters could be combined with EEG data to increase sleepiness and stress detection [39]. In addition to vigilance detection in drivers, HRV could also be used to predict epileptic seizures, thus improving traffic safety [52].

Nonetheless, careful and standardized interpretation of HRV measurements is required, as many factors could influence it. First of all, time-domain and frequency-domain parameters could vary according to the length of the analyzed segment. Thus, variables measured from different length recordings should be compared cautiously. In addition, advanced age could be associated with lower HRV values [9]. In one study, women exhibited lower time-domain parameters and higher HF, reflecting the parasympathetic activity [53]. Moreover, HRV could fluctuate with heart rate, as slower heart rates are associated with higher HRV [9]. For this reason, HRV parameters should be measured according to the existing guidelines [3], so that reported results would be comparable between studies.

All studies included in our systematic review were observational, with a small number of participants, thus limiting the results. That is why more and more extensive clinical trials are required to confirm these data.

5. Conclusions

HRV represents a potentially valuable marker for sleepiness, fatigue, and stress monitoring in drivers. HRV measurements could be implemented in future clinical models and sensors to detect early sleepiness and fatigue and prevent car crashes. More studies with larger populations are needed to support this evidence.

Author contributions

AB and AC conceived and designed the study; CB, and AB performed the data aquisition; CB and ABr analyzed the data; CB and AB wrote the paper; ABr and AC revised the paper.

Ethics approval and consent to participate

Not applicable.

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Conflict of interest

The authors declare no conflict of interest.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at https://rcm.imrpress.com/EN/10.31083/j.rcm2203090.

References

[1] Natarajan A, Pantelopoulos A, Emir-Farinas H, Natarajan P. Heart rate variability with photoplethysmography in 8 million individuals: a cross-sectional study. Lancet Digital Health. 2020; 2: e650–e657.

[2] Kim H, Cheon E, Bai D, Lee YH, Koo B. Stress and Heart Rate Variability: a Meta-Analysis and Review of the Literature. Psychiatry Investigation. 2019; 15: 235–245.

[3] Camm AJ, Malik M, Bigger JT, Breithardt G, Cerutti S, Cohen RJ, *et al.* Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Circulation. 1996; 93: 1043–1065.

[4] Thio CHL, van Roon AM, Lefrandt JD, Gansevoort RT, Snieder H. Heart Rate Variability and its Relation to Chronic Kidney Disease: Results from the PREVEND Study. Psychosomatic Medicine. 2018; 80: 307–316.

[5] Ernst G. Heart-Rate Variability-More than Heart Beats? Frontiers in Public Health. 2017; 5: 240.

[6] Hirsch G, Jensen SH, Poulsen ES, Puthusserypady S. Atrial fibrillation detection using heart rate variability and atrial activity: a hybrid approach. Expert Systems with Applications. 2021; 169: 114452.

[7] Hämmerle P, Eick C, Blum S, Schlageter V, Bauer A, Rizas KD, *et al.* Heart Rate Variability Triangular Index as a Predictor of Cardiovascular Mortality in Patients with Atrial Fibrillation. Journal of the American Heart Association. 2020; 9: e016075.

[8] Drawz PE, Babineau DC, Brecklin C, He J, Kallem RR, Soliman EZ, *et al.* Heart Rate Variability is a Predictor of Mortality in Chronic Kidney Disease: a Report from the CRIC Study. American Journal of Nephrology. 2013; 38: 517–528.

[9] Shaffer F, Ginsberg JP. An Overview of Heart Rate Variability Metrics and Norms. Frontiers in Public Health. 2017; 5: 258.

[10] Goldberger JJ, Challapalli S, Tung R, Parker MA, Kadish AH. Relationship of heart rate variability to parasympathetic effect. Circulation. 2001; 103: 1977–1983.

[11] Sacha J. Interaction between heart rate and heart rate variability. Annals of Noninvasive Electrocardiology. 2014; 19: 207–216.

[12] Chua EC, Tan W, Yeo S, Lau P, Lee I, Mien IH, *et al.* Heart rate variability can be used to estimate sleepiness-related decrements in psychomotor vigilance during total sleep deprivation. Sleep. 2012; 35: 325–334.

[13] Taranto Montemurro L, Floras JS, Picton P, Kasai T, Alshaer H, Gabriel JM, *et al.* Relationship of Heart Rate Variability to Sleepiness in Patients with Obstructive Sleep Apnea with and without Heart Failure. Journal of Clinical Sleep Medicine. 2014; 10: 271–276.

[14] Escorihuela RM, Capdevila L, Castro JR, Zaragozà MC, Maurel S, Alegre J, *et al.* Reduced heart rate variability predicts fatigue severity in individuals with chronic fatigue syndrome/myalgic encephalomyelitis. Journal of Translational Medicine. 2020; 18: 4.

[15] Furman GD, Baharav A, Cahan C, Akselrod S. Early detection of falling asleep at the wheel: a Heart Rate Variability approach. 2008 Computers in Cardiology. 2008; 1109–1112.

[16] Salvati L, d'Amore M, Fiorentino A, Pellegrino A, Sena P, Villecco F. On-Road Detection of Driver Fatigue and Drowsiness during Medium-Distance Journeys. Entropy. 2021; 23: 135.

[17] Hartley LR, El Hassani J. Stress, violations and accidents. Applied Ergonomics. 1994; 25: 221–230.

[18] Watling CN, Mahmudul Hasan M, Larue GS. Sensitivity and specificity of the driver sleepiness detection methods using physiological

signals: a systematic review. Accident Analysis & Prevention. 2021; 150: 105900.
[19] Sikander G, Anwar S. Driver Fatigue Detection Systems: a Review. IEEE Transactions on Intelligent Transportation Systems. 2019; 20: 2339–2352.
[20] Bier L, Wolf P, Hilsenbek H, Abendroth B. How to measure monotony-related fatigue? A systematic review of fatigue measurement methods for use on driving tests. Theoretical Issues in Ergonomics Science. 2020; 21: 22–55.
[21] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, *et al.* The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. British Medical Journal. 2021; 372: n71.
[22] Ma L, Wang Y, Yang Z, Huang D, Weng H, Zeng X. Methodological quality (risk of bias) assessment tools for primary and secondary medical studies: what are they and which is better? Military Medical Research. 2020; 7: 7.
[23] Abtahi F, Anund A, Fors C, Seoane F, Lindecrantz K. Association of Drivers' sleepiness with heart rate variability: a Pilot Study with Drivers on Real Roads. In Eskola H, Väisänen O, Viik J, Hyttinen J (eds.) EMBEC & NBC 2017 (pp 149–152). Singapore: Springer. 2017.
[24] Buendia R, Forcolin F, Karlsson J, Arne Sjöqvist B, Anund A, Candefjord S. Deriving heart rate variability indices from cardiac monitoring-an indicator of driver sleepiness. Traffic Injury Prevention. 2019; 20: 249–254.
[25] Fujiwara K, Abe E, Kamata K, Nakayama C, Suzuki Y, Yamakawa T, *et al.* Heart Rate Variability-Based Driver Drowsiness Detection and its Validation with EEG. IEEE Transactions on Biomedical Engineering. 2019; 66: 1769–1778.
[26] Li G, Chung W. Detection of driver drowsiness using wavelet analysis of heart rate variability and a support vector machine classifier. Sensors. 2013; 13: 16494–16511.
[27] Hendra M, Kurniawan D, Vina Chrismiantari R, Pambudi Utomo T, Nuryani N. Drowsiness detection using heart rate variability analysis based on microcontroller unit. Journal of Physics: Conference Series. 2019; 1153: 012047.
[28] Lee HB, Kim JS, Kim YS, Baek HJ, Ryu MS, Park KS. The relationship between HRV parameters and stressful driving situation in the real road. 2007 6Th International Special Topic Conference on Information Technology Applications in Biomedicine. 2007; 198–200.
[29] Mahachandra M, Yassierli, Sutalaksana IZ, Suryadi K. Sensitivity of heart rate variability as indicator of driver sleepiness. 2012 Southeast Asian Network of Ergonomics Societies Conference (SEANES). 2012; 1–6.
[30] Michail E, Kokonozi A, Chouvarda I, Maglaveras N. EEG and HRV markers of sleepiness and loss of control during car driving. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2008; 2008: 2566–2569.
[31] Murata A, Hiramatsu Y. Evaluation of Drowsiness by HRV Measures: Basic Study for Drowsy Driver Detection. IEEE SMC Hiroshima Chapter. 2008; 2008: 99–102.
[32] Patel M, Lal SKL, Kavanagh D, Rossiter P. Applying neural network analysis on heart rate variability data to assess driver fatigue. Expert Systems with Applications. 2011; 38: 7235–7242.
[33] Persson A, Jonasson H, Fredriksson I, Wiklund U, Ahlstrom C. Heart Rate Variability for Driver Sleepiness Classification in Real Road Driving Conditions. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2019; 2019: 6537–6540.
[34] Vicente J, Laguna P, Bartra A, Bailón R. Drowsiness detection using heart rate variability. Medical & Biological Engineering & Computing. 2016; 54: 927–937.
[35] Yu YJ, Yang Z, Oh B, Yeo YK, Liu Q, Huang G, *et al.* Investigation on driver stress utilizing ECG signals with on-board navigation systems in use. 2016 14th International Conference on Control, Automation, Robotics and Vision. 2016; 1–6.
[36] Zhao C, Zhao M, Liu J, Zheng C. Electroencephalogram and electrocardiograph assessment of mental fatigue in a driving simulator. Accident Analysis & Prevention. 2012; 45: 83–90.
[37] Abe E, Fujiwara K, Hiraoka T, Yamakawa T, Kano M. Development of Drowsiness Detection Method by Integrating Heart Rate Variability Analysis and Multivariate Statistical Process Control. SICE Journal of Control, Measurement, and System Integration. 2016; 9: 10–17.
[38] Li Z, Jiao K, Chen M, Yang Y, Wang C, Qi S. Spectral Analysis of Heart Rate Variability as a Quantitative Indicator of Driver Mental Fatigue. SAE Transactions. 2002; 111: 249–253.
[39] Awais M, Badruddin N, Drieberg M. A Hybrid Approach to Detect Driver Drowsiness Utilizing Physiological Signals to Improve System Performance and Wearability. Sensors. 2017; 17: 1991.
[40] Rodriguez-Ibañez N, García-Gonzalez MA, Cruz MAFdl, Fernández-Chimeno M, Ramos-Castro J. Changes in heart rate variability indexes due to drowsiness in professional drivers measured in a real environment. 2012 Computing in Cardiology. 2012. 913–916.
[41] Bosch. Driver drowsiness detection. Available at: https://www.bosch-mobility-solutions.com/en/solutions/assistance-systems/driver-drowsiness-detection/ (Accessed: 28 June 2021).
[42] Raju JVVSN, Rakesh P, Neelima N. Driver Drowsiness Monitoring System. Intelligent Manufacturing and Energy Sustainability. 2020; 8: 675–683.
[43] Wikipedia TFE. Driver drowsiness detection. 2021. Available at: https://en.wikipedia.org/wiki/Driver_drowsiness_detection (Accessed: 28 June 2021).
[44] Hillebrand S, Gast KB, de Mutsert R, Swenne CA, Jukema JW, Middeldorp S, *et al.* Heart rate variability and first cardiovascular event in populations without known cardiovascular disease: meta-analysis and dose-response meta-regression. EP Europace. 2013; 15: 742–749.
[45] Kubota Y, Chen LY, Whitsel EA, Folsom AR. Heart rate variability and lifetime risk of cardiovascular disease: the Atherosclerosis Risk in Communities Study. Annals of Epidemiology. 2017; 27: 619–625. e612.
[46] Sessa F, Anna V, Messina G, Cibelli G, Monda V, Marsala G, *et al.* Heart rate variability as predictive factor for sudden cardiac death. Aging. 2018; 10: 166–177.
[47] Reyes I, Nazeran H, Franco M, Haltiwanger E. Wireless photoplethysmographic device for heart rate variability signal acquisition and analysis. Annual International Conference of the IEEE Engineering in Medicine and Biology Society. 2012; 2012: 2092–2095.
[48] Drury RL. HRV in an Integrated Hardware/Software System Using Artificial Intelligence to Provide Assessment, Intervention and Performance Optimization. In Aslanidis T (ed.) Autonomic Nervous System Monitoring. London, UK: IntechOpe. 2019.
[49] Hinde K, White G, Armstrong N. Wearable Devices Suitable for Monitoring Twenty Four Hour Heart Rate Variability in Military Populations. Sensors. 2021; 21: 1061.
[50] Osaka M, Murata H, Fuwamoto Y, Nanba S, Sakai K, Katoh T. Application of heart rate variability analysis to electrocardiogram recorded outside the driver's awareness from an automobile steering wheel. Circulation Journal. 2008; 72: 1867–1873.
[51] Schnell I, Potchter O, Epstein Y, Yaakov Y, Hermesh H, Brenner S, *et al.* The effects of exposure to environmental factors on Heart Rate Variability: an ecological perspective. Environmental Pollution. 2013; 183: 7–13.
[52] Moridani MK, Farhadi H. Heart rate variability as a biomarker for epilepsy seizure prediction. Bratislavske Lekarske Listy. 2017; 118: 3–8.
[53] Koenig J, Thayer JF. Sex differences in healthy human heart rate variability: a meta-analysis. Neuroscience & Biobehavioral Reviews. 2016; 64: 288–310.

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Communication

Artificial Intelligence Component of the FERODATA AI Engine to Optimize the Assignment of Rail Freight Locomotive Drivers

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Abstract: The optimization of locomotive drivers' scheduling in rail freight transportation comes as a necessity for minimizing economic expenses and training investments. The Ferodata AI engine, an artificial intelligence (AI)/machine learning (ML) software module, developed by our team, has integrated a supervised random forest model that automatically assigns conductors to freight transportation orders based on the data about locomotive driver's tiredness score, distance of the driver to the departure point of a transportation order, driver availability, and circulation history. The model proposed by us obtained very good performance metrics on the train set (accuracy: 95%, AUC: 0.9905) and reasonably good and encouraging performance on the test set (accuracy: 84%, AUC: 0.8357). After rigorous testing and validation on external and larger datasets, the automated optimization of locomotive driver assignments could bring operational efficiency, cost savings, regulatory compliance, and improved safety to scheduled rail freight transports.

Keywords: rail freight transportation; machine learning; optimal locomotive driver assignment; artificial intelligence

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1. Introduction

A locomotive engineer (driver) is an essential human resource without which a freight train cannot be set in motion [1]. Currently, in Romania, there is still no efficient, automated system to optimize the assignment of engineers to freight trains [2].

Expensive and ample training is provided to all employees in the railway industry, with a particularly rigorous focus on conductors and engineers who operate freight trains [3]. Aspiring engineers are required to undergo comprehensive training that can span over several months, combining intensive classroom instruction, real-world practical training, and regular assessments [4].

The optimization of human resource scheduling in rail freight transportation comes as a necessity for minimizing economic expenses and training investments [5]. However, creating an automated system for engineer assignment is not an easy task.

In the process of allocating locomotive drivers for railway transport, the traffic dispatcher of a railway company must take into account a set of strict legal regulations as well as a set of constraints related to optimizing the use of human resources [6]. Thus, each driver allocated to operate a train on a specific route must meet the requirement regarding the maximum driving/service time, as well as rest time and place. The driving/service times are strictly dependent on the rest time since the last service and the location where the driver claims to have rested. The resting place can be at home or another location if the engineer is in transit.

It should be considered that, in the railway transport process, the company uses a set of dispatch points where trains are formed and where the locomotive drivers' service begins [7]. These dispatch points can be located in the engineer's hometown or elsewhere.

The traffic dispatcher must effectively utilize the locomotive engineer human resource, which is not available in the necessary proportions for railway transport activities, in order to carry out commercial transport operations, while simultaneously complying with all legal requirements and minimizing their overburdening or rest in places other than their domicile [7].

Several papers published so far tackled the subject of automation in railway crew scheduling. One commonly used approach is to employ complete enumeration to generate all possible candidates that satisfy the given constraints and, afterward, apply integer linear programming to solve the problem [8] of crew scheduling in transit systems. Additionally, heuristic methods are widely adopted. In the domain of public transport driver scheduling, a combined approach employing both integer linear programming and heuristics was proposed [9]. Li and Kwan [10,11] proposed a greedy/heuristic approach integrated with a fuzzy genetic algorithm. Frisch et al. [12] introduced a matheuristic approach. Froger et al. [13] presented a solution strategy that combines Lagrangian relaxation with subgradient optimization. Another highly effective method is column generation [14]. A noteworthy study focuses on applying a column generation technique to optimize periodic rail crew schedules [15].

To our knowledge, none of the papers published to date considered methods based on artificial intelligence (AI)/machine learning (ML) for the automatic allocation of locomotive drivers to scheduled transportation orders. Compared to heuristic techniques, ML models could bring the advantage of firstly time efficiency [16], as only the training of the ML models is time-consuming. Once the model is trained, querying the model in practice is performed in no time, while heuristic solutions may be complex and slow. Secondly, they are reliable, as they learn from past experience: the greater the experience, the more efficient the algorithms [17]. On the other hand, heuristic algorithms will not improve their performance over time. They are flexible [18]: AI systems can adapt to changing conditions, such as unexpected delays or new orders by continuously reevaluating and adjusting assignments in real-time. Heuristic approaches may require manual adjustments to accommodate changes. Finally, AI scalability is advantageous: AI solutions can scale to handle many more transportation orders after the model is trained. Heuristic methods may struggle to handle such complexity effectively.

In the current Romanian freight railway system, the allocation of locomotive drivers is carried out manually by designated dispatchers that invest time, great effort, and are exposed to the risk of fatigue and subsequent human error. An AI solution could replace the heavy manual work of the rail dispatchers and solve several of the limitations of the heuristics methods through an automated, time and resource efficient solution for the allocation of locomotive drivers in rail freight transportation.

Moreover, recent special reports from the European Court of Auditors conclude that European freight rail transport is not yet on the right track [19]. Shifting focus from roads and increasing the utilization of alternative freight transportation modes, such as railways, can significantly contribute to making freight transport more environmentally friendly (greener) [19]. There are currently numerous European policies and strategies aimed to transform rail cargo transportation to a more competitive alternative [19]. Our paper aligns with the current European Union effort by proposing an AI/ML method to optimize resource management in rail freight transports.

Our team worked on a software application, the Ferodata system, that captures the technical–dynamic sensory information of the locomotive, based on which it creates the circulation history of the locomotive/train to which it is associated. The circulation history presents, in chronological order, the passing stations, the station stop times, as well as the fuel consumption/electric energy consumption associated with the section of the route. Through the Ferodata mobile application, the locomotive driver reports the rest time and

location at the beginning of each service. These pieces of information are accumulated in the Ferodata system within the performance history. By correlating the performance history with the circulation history, the location of each driver and the route to the current location can be determined. From the circulation history, the route of travel and the required driving times to reach the destination can also be deduced. Thus, the whereabouts of each driver can be known at any given moment, as well as the current driving/service times. Furthermore, it is possible to analyze the working hours situation per workplace, period, and locomotive driver.

We aimed to develop and add to our Ferodata AI engine an innovative AI/ML module that automatically assigns locomotive engineers to freight transportation orders based on collected data such as circulation history and drivers' availability, service time and current location. The module is built to optimize the number of drivers and the amount of service times while complying with the legal regulations. Our final aim is to replace the manual work of rail dispatchers, bringing significant economical and resource management benefits to railway companies and better experience and satisfaction for the final clients.

2. Materials and Methods

2.1. Study Design

A retrospective study was conducted on a sample of 64,768 historical transportation order records. All data were obtained from the database of a Romanian freight railway transportation company. The access to the database was due to our contractual collaboration for the development of the Ferodata software (version 1). More information about the data presented in this study is available on request from the corresponding author.

Data for all transportation orders between the 1 August 2021 and the 30 June 2022 were fetched.

2.2. Data Collection

The following data regarding freight transportation orders were collected for the study from the historical activity of the locomotives: activity start and end dates, start railway station, end railway station, registration number, the assigned driver for that transportation order (the label), location (latitude and longitude) of all the drivers before each transportation order start date, number of working hours of all drivers in the week prior the transportation order start date, and whether at the moment of activity start date the engineers were on medical or annual leave.

The labeling process consisted of several steps. Firstly, all the necessary information about the freight transportation orders (including departure time, departure place, destination) and driver availability (work hours, days off, location with distance to the transportation orders departure place) was collected. Secondly, scheduling started with a blank timetable that represents the available time slots for transportation orders for the next week. The adding of the assignments followed a systematized approach by exhaustive search in the space of all possible assignments that respect legal regulations. The exhaustive search was needed to ensure the optimization of several parameters for the current week: minimization of the number of assigned drivers, maximization of the time spent driving the locomotives (less time spent by the drivers commuting to the place of departure), and fair distribution of work time to all drivers involved. The exact technical details of the manual implementation of driver assignment are confidential data belonging to the railway company and cannot be disclosed in full. Consistency in the labeling process was warranted by weekly quality checks made by appointed control officers and performance evaluators that had to ensure the dispatchers were correctly following the company's protocol for driver assignments. Although this optimization strategy reduces driving personnel expenses, it is also very time expensive and overloads dispatchers. This prompted the need for an automatic solution that can learn from all the labels manually assigned thus far.

2.3. Problem Statement

Our research paper proposes a technical solution that automatically assigns drivers to locomotives for the current work week in a way that optimizes the previously mentioned three parameters: number of assigned drivers, time spent driving the locomotives, and fair distribution of work time to all drivers involved, while complying with the legal regulations.

2.4. Study Protocol

Each record from the study's dataset has three defined columns (two attributes and the outcome variable). The two attributes are: the tiredness score (=the number of working hours of a driver in the week prior to a transportation order start date) and the distance to the departure point (in km) of a scheduled transport. The outcome variable is also a binary variable illustrating whether a driver was assigned to that transportation order or not.

For the current phase of the study, we define the following constraints: a driver should not have more than 40 h of work in a week and should not be on medical or annual leave. Furthermore, we currently assume that driver preferences are not taken into account and there is no enroute change of drivers. In future studies, we will integrate driver preferences and the possibility of enroute change of drivers as parameters for the training of our models.

The records belonging to drivers that are on medical or annual leave at the moment of a scheduled transportation order are excluded from the dataset.

The documented continuous variables were normalized in the range [0, 1].

The initial dataset consisting of 64,768 records was randomly divided into a training set of 51,814 records (80%) and a test set of 12,954 records (20%).

Random forest (RF) and multi-layer perceptron (MLP) classifiers were developed. In RStudio, we utilized the caret::train function to construct the models, taking precautions to prevent overfitting by implementing 10-fold cross-validation. Implementation and mathematical details behind caret models in R are publicly available and can be consulted in the online documentation [20]. To handle imbalanced output classes, we applied the synthetic minority over-sampling technique (SMOTE) alongside the caret::train function. In order to ensure the study's replicability, Table 1 provides an overview of the parameters passed to the caret::train function.

Table 1. Parameters used to train the ML models with the caret::train function.

Method	**"rf"/"mlpML"**
preProcess	c("scale", "center")
trControl	trainControl(method = "repeatedcv", number = 10, repeats = 10, sampling = "smote")

The sigmoid function was used as the transfer function for the MLP model. The caret::train function automatically tuned three hyperparameters for the mlpML method and one hyperparameter for the RF method. The automatically tuned parameters were the number of neurons in each of the three hidden layers corresponding to the mlpML method design and mtry corresponding to the RF method. The hyperparameters were tuned so as to maximize the model's accuracy. A detailed implementation flow chart of the RF and MLP classifiers is illustrated in Figure 1.

The RF and MLP binary models were developed to predict whether an available locomotive driver should be assigned for a scheduled transportation order considering the current distance to the departure location and the tiredness score. The performance metrics of the RF and MLP models are compared and the algorithm with the highest accuracy is chosen to be integrated into the platform.

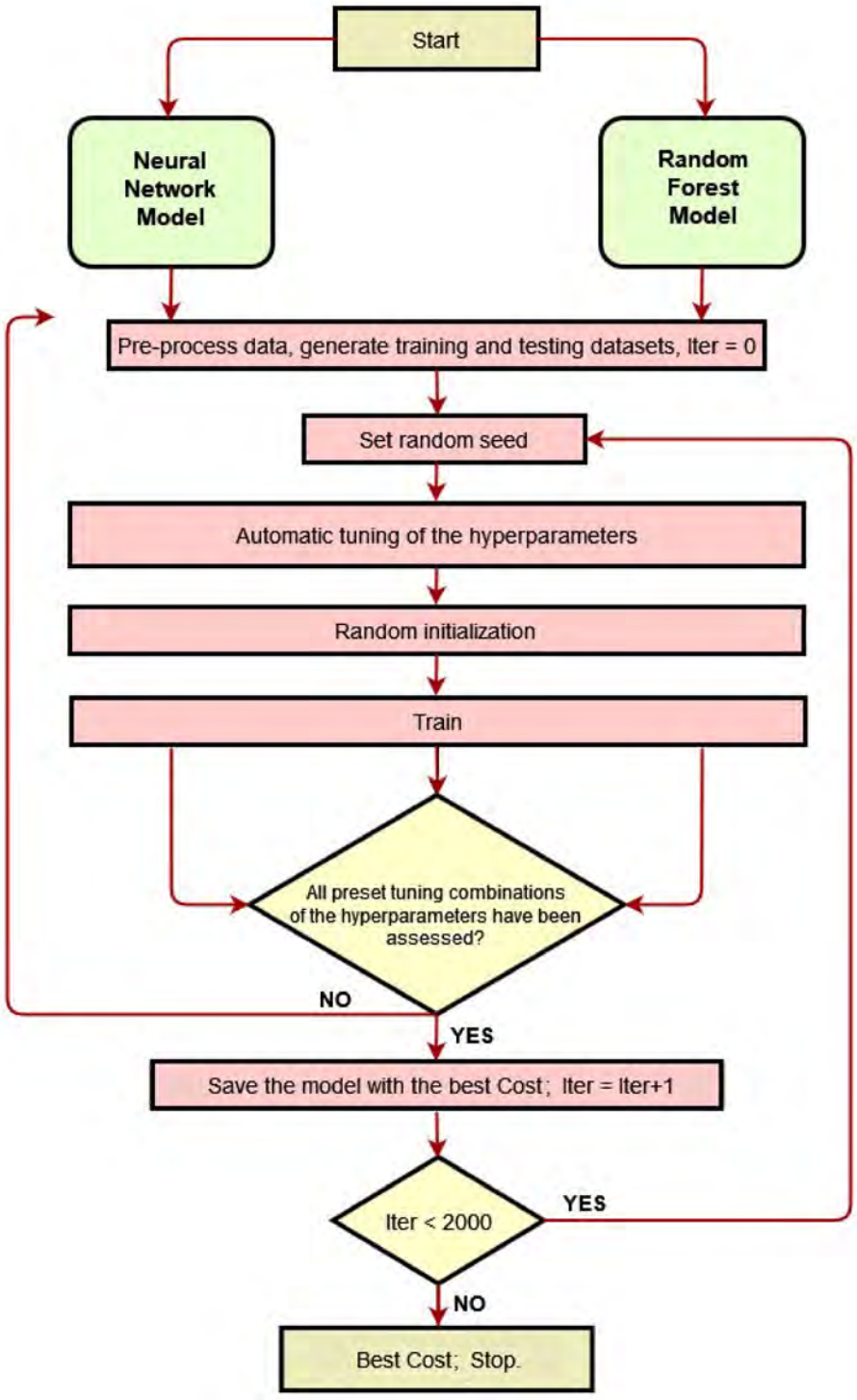

Figure 1. Implementation flow chart of the random forest and multi-layered perceptron models.

Depending on the availability, tiredness score at the moment of the freight transportation order, and distance to the departure point, the driver recommended to the dispatcher for assignment to each transport order is chosen based on the highest probability determined by the chosen ML model.

If a driver already has 40 h of work in the week prior to a scheduled freight expedition or it are on medical or annual leave, they are automatically declared unavailable before querying the ML model.

The preprocessing and models' implementation are performed in RStudio version 2023.03.0+386 (3c53477a, 2023-03-09) for Windows.

Validation of our ML model is a critical step in the development process to ensure that the model can generalize well to new, unseen data. It involves assessing the performance and reliability of the model using data that it has not seen during training. The main goal of validation is to estimate how well the model is expected to perform on new, real-world data. Therefore, we assessed the classification accuracy of the ML models on the test set, as it contains only new, unseen data. We also calculated metrics such as the area under the ROC curve (AUC), sensitivity, specificity, as well as positive predictive values (PPV) and negative predictive values (NPV).

3. Results

The selection of the optimal driver in terms of tiredness score, availability, and distance to the departure railway point was performed according to supervised random forest mathematical optimization in R.

The training of the mathematical optimizer was carried out on 51,814 records and testing on the unseen data was carried out on 12,954 records from the collected Unicom Tranzit data.

For the sake of transparency, we present the first 10 records from the training set in Table 2.

Table 2. The first 10 records from the training set.

Tiredness Score	Distance to Departure Point (km)	Driver Was Selected for the Transport Order (1—'Yes', 0—'No')
0.54	180.94	0
6.53	142.61	0
0	80.5	1
24.17	77.56	0
35.24	70.94	0
33.53	96.175	0
26.08	27.18	1
23.16	98.37	0
17.46	151.76	0
19.93	77.14	0

A summary of the continuous parameters of the whole dataset is presented in Table 3. Additionally, we present the information that summarizes the train set and the test set in Tables 4 and 5, respectively. No significant differences were found between the training and test sets regarding each of the collected parameters (continuous or categorical). Numerical data are presented as median with interquartile range, due to the non-normal distribution. Categorical data are described by number of occurrences and percentage.

After the training step, we obtained the RF and MLP models that we tested on both the training set and the test set (unseen data).

Table 3. Summary of the parameters of the whole dataset.

	Tiredness Score	Distance to Departure Point	Driver Was Selected for the Transport Order
Min	0	0	
1st interquartile range	0	65.75	
Median	6.28	105.15	12,933 (19.97%)
3rd interquartile range	18.6	152.35	
Max	61	313.85	

Table 4. Summary of the parameters of the training set.

	Tiredness Score	Distance to Departure Point	Driver Was Selected for the Transport Order
Min	0	0	
1st interquartile range	0	49.98	
Median	5.51	120.84	10,412 (20.09%)
3rd interquartile range	20.3	159.12	
Max	59.8	313.85	

Table 5. Summary of the parameters of the test set.

	Tiredness Score	Distance to Departure Point	Driver Was Selected for the Transport Order
Min	0	0	
1st interquartile range	0	71.51	
Median	7.02	98.32	2571 (19.85%)
3rd interquartile range	16.98	149.76	
Max	61	310.2	

After obtaining the RF model, the request to display it in Rstudio results in the following Rstudio console response, which demonstrates the main parameters and training performance of the model (10-fold cross validation, 10 repeats, a mtry value of 2, accuracy of 0.8880513, and a kappa value of 0.6320161):

```
Random Forest
Pre-processing:  scaled (2), centered (2)
Resampling:  Cross-Validated (10 fold, repeated 10 times)
Additional sampling using SMOTE prior to pre-processing

Resampling results:

Accuracy Kappa
0.8880513 0.6320161

Tuning parameter 'mtry' was held constant at a value of 2
```

The performance metrics on the training and test sets for the RF model are illustrated in Table 6.

Table 6. The performance metrics of the RF model on the training and test sets.

	Random Forest	
	Train Set	**Test Set**
Accuracy	99%	88%
95% CI	(0.9847, 0.9932)	(0.8549, 0.9079)
p value	<0.001	0.001
Sensitivity	99%	92%
Specificity	99%	72%
PPV	100%	94%
NPV	95%	63%
AUC	0.9927	0.8998

The ROC curves of the RF classifier for both the training and test sets can be visualized in Figure 2.

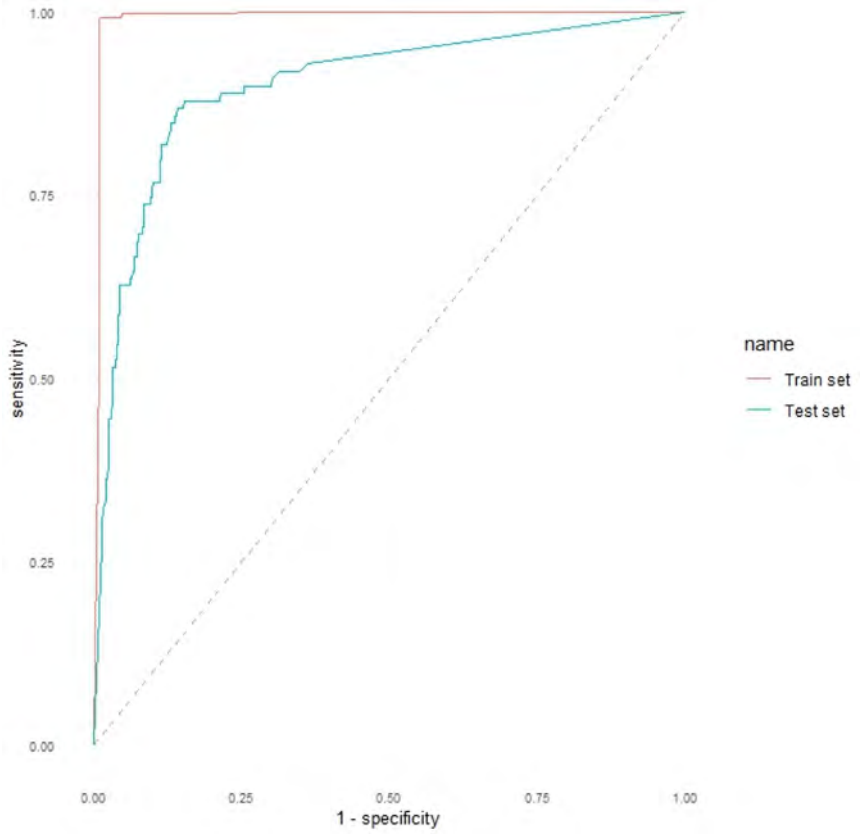

Figure 2. ROC curves obtained by the RF model on the training and test sets.

After obtaining the MLP model, we displayed it in the RStudio console, in a similar manner as we did with the RF classifier, and we obtained the following result. This result also demonstrates the main parameters and training performance of the model (10-fold cross validation, 10 repeats, preprocessing modes, one hidden layer containing five neurons, and accuracy and kappa values for the different numbers of neurons in the hidden layer):

```
_____________________________________
Multi-Layer Perceptron, with multiple layers

2 predictor
2 classes:  '0', '1'

Pre-processing:  scaled (2), centered (2)
Resampling:  Cross-Validated (10 fold, repeated 10 times)
Additional sampling using SMOTE prior to pre-processing

Resampling results across tuning parameters:

layer1 Accuracy Kappa
1 0.8107440 0.4717333
3 0.8100957 0.4679649
5 0.8390885 0.5161155

Tuning parameter 'layer2' was held constant at a value of 0
Tuning parameter 'layer3' was held constant at a value of 0
Accuracy was used to select the optimal model using the
largest value.
```

```
    The final values used for the model were layer1 = 5,
layer2 = 0 and layer3 = 0.
```

The performance metrics on the training and test sets for the MLP model are illustrated in Table 7.

Table 7. The performance metrics of the MLP model on the training and test sets.

	Multi-Layer Perceptron	
	Train Set	**Test Set**
Accuracy	85%	86%
95% CI	(0.8346, 0.8637)	(0.8278, 0.8852)
p value	0.045	0.012
Sensitivity	86%	89%
Specificity	78%	73%
PPV	95%	94%
NPV	53%	58%
AUC	0.8994	0.8857

The ROC curves of the MLP classifier for both the training and test sets are illustrated in Figure 3.

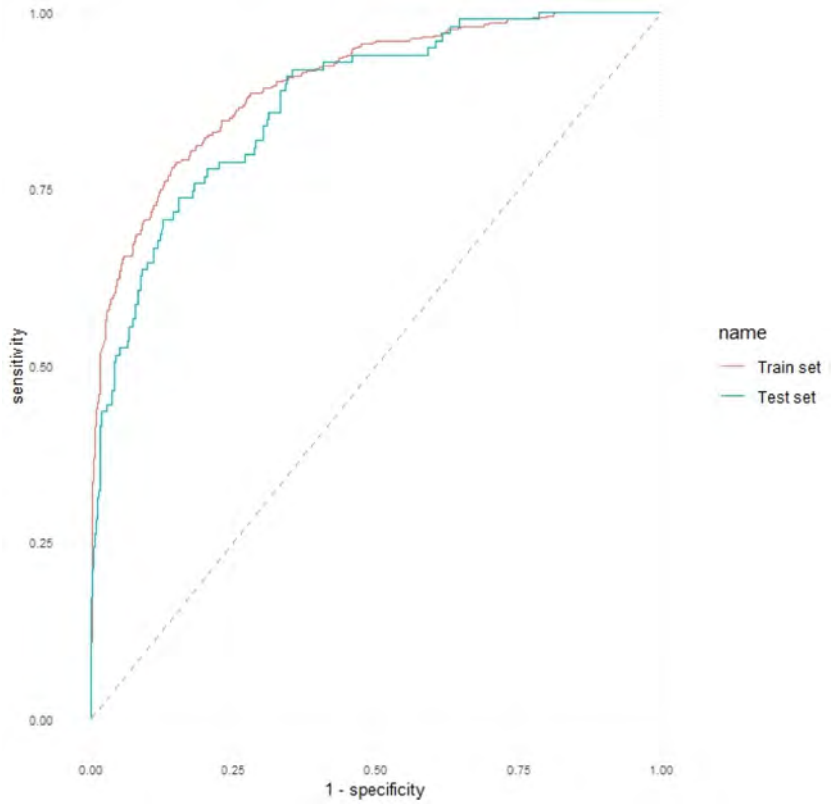

Figure 3. ROC curves obtained by the MLP model on the training and test sets.

As can be seen from the comparison of the RF versus MLP models, the RF classifier achieved higher performance metrics (accuracy, AUC) on both the training and test sets. Therefore, the RF model was chosen to be integrated into the platform.

For each transport order, the driver that is available and has the highest probability of being chosen by the RF model, is selected to be recommended to the dispatcher for assignation to the transport order.

In order to exemplify the practical use of our model, we present in Table 8 two real-world use cases/scenarios.

Table 8. Illustration of two real-world use cases.

Scenarios	Date of Scheduled Transportation Order	Departure Point	Destination Point	The Driver Manually Assigned by the Dispatcher	The Driver Recommended by Our Platform
Scenario 1	1 June 2022, 00:36	PLOIESTI VEST	BASARABI	Anonymized driver 4	Anonymized driver 4
		Result: The platform decision matched the human decision.			
Scenario 2	31 May 2022, 17:14	GHERLA	AIUD	Anonymized driver 12	Anonymized driver 12
		Result: The platform decision matched the human decision.			

For the transportation order scheduled on 1 June 2022 at 00:36, destined to depart from PLOIESTI VEST to BASARABI, the dispatcher manually assigned as driver: anonymized driver 4. The platform was run, and it also recommended as driver: anonymized driver 4. Therefore, the platform decision matched the human decision. This proves that we achieved our goal to develop an automatic module that could replace the manual work of assigning drivers to a locomotive, that is nowadays performed by the dispatcher.

4. Discussion

The Ferodata AI optimization module retrieves data from the database, performs a forecast regarding the most suitable locomotive driver to be allocated for expeditions considering the location of the driver, rest time, and availability. It should be considered that, as new data are gathered, the model will undergo retraining and retesting in order to improve its performance.

The locomotive driver serves as a vital link within the rail transport chain and holds an integral role in its operations [21]. Nevertheless, this profession has encountered a range of challenges in recent years [22]. Factors such as a persistent shortage of qualified drivers, mounting stress levels, and deteriorating working conditions have arisen [23]. As a result, there exist substantial opportunities for innovating the organization of this job position [24].

Our study aimed to propose an effective and innovative method to improve the management of this job position, in the current context. To our knowledge, there has been no scientific paper published to date that proposed a random forest model for automatic allocation of drivers on rail freight transportation orders.

The model proposed by us obtained excellent performance metrics on the train set (accuracy: 99%, AUC: 0.9927) and very good and encouraging performance metrics on the test set (accuracy: 88%, AUC: 0.8998). With the increase in the size of the database and access to more variables (driver skills, driver preferences, enroute change of drivers, etc.), the model will be retrained and improved.

The ML model proposed by us provides several valuable contributions to the logistics of rail freight transportation industry: optimized resource allocation, reduced human error, cost savings (minimize labor cost), real-time adaptability, scalability, and ensuring compliance with industry regulations, safety standards, and labor laws.

Consistent scientific evidence shows that the primary outcome of economic significance would be the reduction in costs through the efficient utilization of train resources, particularly train personnel, including vehicle drivers [25]. Efficient driver assignment through automation can lead to cost savings by reducing overtime expenses, optimizing resource utilization, and minimizing disruptions due to unplanned driver unavailability [26].

It also allows for better planning of driver schedules and potential reduction in the need for additional staff [27].

Automation allows for the optimization of driver assignments based on various factors such as availability, and rest requirements. This leads to more efficient utilization of resources and reduces idle time or unnecessary delays in the transport process [28]. Automated optimization helps in maximizing productivity by ensuring that drivers are consistently engaged in transporting freight. This results in improved overall efficiency, better resource allocation and a balanced workload distribution in the rail freight operations, preventing underutilization or overburdening of drivers.

The planning and execution processes can be simplified by handling the complex task of driver assignment. It eliminates manual or ad-hoc approaches, enabling faster decision-making and reducing administrative burdens. The system can generate optimized driver schedules, taking into account factors such as transport requirements, driver availability, and regulatory constraints. The system could easily be configured to consider and enforce regulatory requirements such as maximum driving times, rest periods, and other labor regulations [29]. By automating the assignment process, it helps ensure compliance with these regulations, minimizing the risk of violations and associated penalties.

Regarding safety, the system can also help manage driver fatigue, ensuring that drivers are adequately rested and capable of safely operating the locomotives. This contributes to maintaining a high level of safety in rail freight operations.

Real-time adaptability is another advantage of using an automated optimization system [30]. When disruptions occur, such as driver unavailability due to illness or unexpected events, automated optimization systems can quickly analyze the situation and reassign available drivers to fill the gaps [31]. By identifying the most suitable replacements based on various factors like tiredness score, proximity, and regulatory compliance, the system minimizes the impact of disruptions on the overall schedule. In the event of disruptions along a specific route or at a particular location, the automated optimization system can rapidly reallocate an optimal driver for the alternative routing by analyzing available drivers and resources, ensuring timely delivery, and minimizing the impact of disruptions on the entire transport network.

Limitations

Firstly, one of the primary limitations of our study is the degree of data availability for the automated optimization. Access to comprehensive and accurate data on company's key performance indicators, driver skills, driver preferences, enroute change of drivers, etc. would allow for a more complex analysis and the more realistic modeling of real-life scenarios. One of our future prospects is to integrate such parameters (when available) in the training or testing of our models. Secondly, our dataset size is rather small, making us uncertain on the model's behavior on large-scale optimization problems. Thirdly, the testing of the models was carried out on internal data. Scalability and computational efficiency are yet to be ensured and evaluated on larger and external datasets, which is another future prospect of our research.

5. Conclusions

We presented the Ferodata AI engine, an AI/ML optimization module, developed by our team, that automatically assigns drivers to freight transportation orders based on the data about drivers, workplaces, driving/service times, and circulation history. The model proposed by us is the first of its kind to be published and obtained excellent performance metrics on the train set and very good and encouraging performance metrics on the test set. The presentation of the Ferodata AI engine and the publication of this research paper for the rail freight transportation industry can have several important implications and benefits for the industry as a whole. One of the key benefits of an AI/ML optimization module like the Ferodata AI engine is the potential for significant efficiency improvements. By automatically assigning drivers to freight transportation orders based on various data points, idle time

can be reduced and overall resource allocation can be improved. This leads to cost savings for transportation companies and potentially lower prices for customers. The ability to assign drivers to orders with precision can lead to better service quality. Timely deliveries and reduced delays can enhance customer satisfaction, making rail freight transportation a more attractive option for businesses that rely on it. AI-driven optimization can help rail freight companies make the most of their resources. It can balance workloads, prevent the overworking of certain drivers, and ensure that resources are used efficiently across the network. Optimized driver assignments can also lead to safety improvements. By managing driver schedules and driving times more effectively, it is possible to reduce fatigue-related accidents and enhance overall safety within the industry. By optimizing driver schedules and ensuring compliance with regulations regarding working hours and rest breaks, the Ferodata AI engine can help rail freight companies maintain regulatory compliance and avoid fines or penalties. After rigorous testing and validation on external and larger datasets, the automated optimization of locomotive driver assignments could bring operational efficiency, cost savings, regulatory compliance, and improved safety to scheduled rail freight transports. If the AI/ML optimization module proves successful, it may encourage other rail freight companies to adopt similar technologies. This can lead to an industry-wide shift towards greater efficiency and improved services.

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References

1. Fan, C.; Huang, S.; Lin, S.; Xu, D.; Peng, Y.; Yi, S. Types, Risk Factors, Consequences, and Detection Methods of Train Driver Fatigue and Distraction. *Comput. Intell. Neurosci.* **2022**, *2022*, 8328077. [CrossRef] [PubMed]
2. Insights into the Railway Infrastructure in Romania. Available online: https://china-cee.eu/2023/04/28/romania-social-briefing-insights-into-the-railway-infrastructure-in-romania/ (accessed on 22 May 2023).
3. Europe's Rail Joint Undertaking Multi-Annual Work Programme. Available online: https://rail-research.europa.eu/wp-content/uploads/2021/12/20211222_mawp_v1_agreed-in-principle_clean.pdf (accessed on 25 May 2023).
4. Abbas, Y.; Martinetti, A.; Nizamis, K.; Spoolder, S.; van Dongen, L.A.M. Ready, trainer . . . one*! discovering the entanglement of adaptive learning with virtual reality in industrial training: A case study. *Interact. Learn. Environ.* **2021**, *31*, 3698–3727. [CrossRef]
5. Zhang, X.; Li, L.; Zhang, J. An optimal service model for rail freight transportation: Pricing, planning, and emission reducing. *J. Clean. Prod.* **2019**, *218*, 565–574. [CrossRef]
6. Campos, J.; Cantos, P. Rail Transport Regulation. Available online: https://documents1.worldbank.org/curated/en/284281468764045820/135535322_20041117180643/additional/multi-page.pdf (accessed on 22 May 2023).
7. Janota, A.; Pirník, R.; Ždánsky, J.; Nagy, P. Human Factor Analysis of the Railway Traffic Operators. *Machines* **2022**, *10*, 820. [CrossRef]
8. Han, A.F.; Li, E.C. A constraint programming-based approach to the crew scheduling problem of the Taipei mass rapid transit system. *Ann. Oper. Res.* **2014**, *223*, 173–193. [CrossRef]
9. Fores, S.; Proll, L.; Wren, A. TRACS II: A hybrid IP/heuristic driver scheduling system for public transport. *J. Oper. Res. Soc.* **2002**, *53*, 1093–1100. [CrossRef]

10. Li, J. A Self-Adjusting Algorithm for Driver Scheduling. *J. Heuristics* **2005**, *11*, 351–367. [CrossRef]
11. Li, J.; Kwan, R.S.K. A fuzzy genetic algorithm for driver scheduling. *Eur. J. Oper. Res.* **2003**, *147*, 334–344. [CrossRef]
12. Frisch, S.; Hungerländer, P.; Jellen, A. On a Real-World Railway Crew Scheduling Problem. *Transp. Res. Procedia* **2022**, *62*, 824–831. [CrossRef]
13. Froger, A.; Guyon, O.; Eric, P. *A Set Packing Approach for Scheduling Passenger Train Drivers: The French Experience*; HAL: Lyon, France, 2015.
14. Heil, J. A Solution Approach for Railway Crew Scheduling with Attendance Rates for Multiple Networks. In Proceedings of the Operations Research Proceedings 2018: Selected Papers of the Annual International Conference of the German Operations Research Society (GOR), Brussels, Belgium, 12–14 September 2018; Springer: Cham, Switzerland, 2019; pp. 547–553.
15. Janacek, J.; Kohani, M.; Koniorczyk, M.; Marton, P. Optimization of periodic crew schedules with application of column generation method. *Transp. Res. Part C Emerg. Technol.* **2017**, *83*, 165–178. [CrossRef]
16. Zongheng, Y. *Machine Learning for Query Optimization*; University of California: Berkeley, CA, USA, 2022.
17. Zhang, C.; Wu, Y.; Ma, Y.; Song, W.; Le, Z.; Cao, Z.; Zhang, J. A review on learning to solve combinatorial optimisation problems in manufacturing. *IET Collab. Intell. Manuf.* **2023**, *5*, e12072. [CrossRef]
18. Wang, H.; Jacob, V.; Rolland, E. Design of efficient hybrid neural networks for flexible flow shop scheduling. *Expert Syst.* **2003**, *20*, 208–231. [CrossRef]
19. ECA. EU Freight Transport: The Truck Continues to Rule. Available online: https://www.eca.europa.eu/Lists/News/NEWS202303_27/INSR-2023-08_EN.pdf (accessed on 5 September 2023).
20. The Caret Package. Available online: https://topepo.github.io/caret/ (accessed on 29 September 2023).
21. Wangai, A.W.; Rohacs, D.; Boros, A. Supporting the Sustainable Development of Railway Transport in Developing Countries. *Sustainability* **2020**, *12*, 3572. [CrossRef]
22. Wang, Z.; Liu, X. Cyber security of railway cyber-physical system (CPS)—A risk management methodology. *Commun. Transp. Res.* **2022**, *2*, 100078. [CrossRef]
23. Hranický, M.P.; Černá, L.; Kuka, A. Application of the Theory of Constraints for Railway Personnel. *Transp. Res. Procedia* **2021**, *53*, 31–38. [CrossRef]
24. Naweed, A.; Chapman, J.; Allan, M.; Trigg, J. It Comes with the Job: Work Organizational, Job Design, and Self-Regulatory Barriers to Improving the Health Status of Train Drivers. *J. Occup. Environ. Med.* **2017**, *59*, 264–273. [CrossRef]
25. Vojtek, M.; Kendra, M.; Zitrický, V.; Široký, J. Mathematical approaches for improving the efficiency of railway transport. *Open Eng.* **2020**, *10*, 57–63. [CrossRef]
26. Andreasson, R.; Jansson, A.A.; Lindblom, J. The coordination between train traffic controllers and train drivers: A distributed cognition perspective on railway. *Cogn. Technol. Work* **2019**, *21*, 417–443. [CrossRef]
27. Union Internationale des Chemins de Fer. Final Report Summary—CAPACITY4RAIL (Increasing Capacity 4 Rail Networks through Enhanced Infrastructure and Optimised Operations). Available online: https://cordis.europa.eu/project/id/605650/reporting/it (accessed on 22 May 2023).
28. Khmeleva, E.; Hopgood, A.A.; Tipi, L.; Shahidan, M. Fuzzy-Logic Controlled Genetic Algorithm for the Rail-Freight Crew-Scheduling Problem. *KI—Künstliche Intell.* **2018**, *32*, 61–75. [CrossRef]
29. Demiridis, N.; Pyrgidis, C. Getting freight trains back on track–How railway undertakings, infrastructure owners and regulators can navigate the main dilemmas in freight business to drive sustainable growth. *Front. Sustain.* **2022**, *3*, 903945. [CrossRef]
30. Veelenturf, L.P.; Potthoff, D.; Huisman, D.; Kroon, L.G.; Maróti, G.; Wagelmans, A.P.M. A Quasi-Robust Optimization Approach for Crew Rescheduling. *Transp. Sci.* **2016**, *50*, 204–215. [CrossRef]
31. Brandenburger, N.; Jipp, M. Effects of expertise for automatic train operations. *Cogn. Technol. Work* **2017**, *19*, 699–709. [CrossRef]

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REVIEW
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"Not by Our Feeling, But by Other's Seeing": Sentiment Analysis Technique in Cardiology—An Exploratory Review

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Sentiment Analysis (SA) is a novel branch of Natural Language Processing (NLP) that measures emotions or attitudes behind a written text. First applications of SA in healthcare were the detection of disease-related emotional polarities in social media. Now it is possible to extract more complex attitudes (rank attitudes from 1 to 5, assign appraisal values, apply multiple text classifiers) or feelings through NLP techniques, with clear benefits in cardiology; as emotions were proved to be veritable risk factors for the development of cardiovascular diseases (CVD). Our narrative review aimed to summarize the current directions of SA in cardiology and raise the awareness of cardiologists about the potentiality of this novel domain. This paper introduces the readers to basic concepts surrounding medical SA and the need for SA in cardiovascular healthcare. Our synthesis of the current literature proved SA's clinical potential in CVD. However, many other clinical utilities, such as the assessment of emotional consequences of illness, patient-physician relationship, physician intuitions in CVD are not yet explored. These issues constitute future research directions, along with proposing detailed regulations, popularizing health social media among elders, developing insightful definitions of emotional polarity, and investing research into the development of powerful SA algorithms.

Keywords: sentiment analysis, cardiovascular, artificial intelligence, machine learning, social media

INTRODUCTION

Sentiment Analysis (SA) or "opinion mining" is a novel branch of Natural Language Processing (NLP) that measures emotions or attitudes behind a written text. At the most basic level, SA tools classify pieces of text as having positive, negative, or neutral emotions, although current technologies support much more complex analysis of emotions in the written text (1).

Several artificial intelligence (AI)/machine learning (ML) technologies and other types of computational techniques have been proposed and proved their benefits in bettering diagnostic accuracy and treatment efficacy (2). The existence of intuition and the documentation of its importance in patient management urges the enrichment of medical AI/ML and other computational methods with the ability to detect and assess emotions to attain higher performance

in solving health problems. Using SA to examine doctors' written notes on intensive-care-unit patients, the paper showed that doctors' intuitions ("gut feelings") were an essential factor in determining the disease management for each patient (3).

To further explore the effectiveness of SA in medical context, a review investigating the SA methods used for examining emotions in healthcare tweets has been published (4). However, no review has focused, so far, on evaluating the utility of SA in cardiology. Cardiovascular diseases (CVD) arouse a particular interest as they are the deadliest diseases in the world (5). Recent studies suggest that SA could be extremely useful in cardiology, especially in the context of extensive use of telemedicine due to the COVID-19 pandemic (6).

The increasing use of social platforms may be the foundation for developing SA-based models applied to various fields in cardiology. A study on drug safety showed that adding SA features improves the performance of state-of-the-art methods to identify adverse drug reactions (ADR). These models used a corpus of posts from Twitter and other online forums. SA features significantly increased the F-measure of adverse reaction detection (for 81 drugs, including cardiovascular medication) from 72.14 to 73.22% in the Twitter corpus of posts. The improvement of ADR detection by SA became possible due to the rapidly growing popularity of social media and health forums (7, 8).

Our narrative review aims to: (1) summarize the current directions of SA in cardiology and the results achieved so far in a systematic manner, (2) raise the awareness of cardiologists about the potentiality of this novel and promising domain that will soon become a practical reality, and (3) open new perspectives regarding the dialogue between AI specialists and cardiologists. Given the small number of studies so far, a systematic methodology is not suitable, therefore the purpose of this review is purely narrative.

MATERIALS AND METHODS

We searched PubMed/Medline and Google Scholar for studies in English addressing the topic of SA in cardiology, from inception to february 2022. The following search string was used: ("Sentiment analysis" OR "Emotions recognition" OR "Sentiment recognition") AND ("Heart failure" OR "Cardiac insufficiency" OR "Coronary Artery Disease" OR "CAD" OR "Coronary syndrome" OR "Coronary" OR "Stable angina" OR "Angina pectoris" OR "Ischemic heart disease" OR "IHD" OR "Ischemic" OR "Ischemia" OR "Myocardial infarction" OR "Infarction" OR "Atrial fibrillation" OR "AF" OR "Stroke" OR "Arrhythmia" OR "Heart rate" OR "Pulse" OR "Sudden death" OR "Sudden cardiac death" OR "Cardiovascular prevention").

We reviewed an initial number of 550 studies, and after excluding the duplicates, 498 studies remained. After excluding the studies irrelevant to our objectives, we selected 11 papers that address SA methods focusing on cardiovascular diseases. Papers were included regardless of whether they constituted original research, reviews, opinions, reports. Any type of study was considered eligible for inclusion. Three researchers realized the agreement between the studies selected. All included studies are illustrated in **Table 1**.

The main directions of research regarding SA in cardiology identified from the retained studies are: the identification of emotional risk factors for CVD, the detection of positive/negative attitudes of CV patients toward their disease and its clinical implications, the detection of cardiac arrhythmia, the triage of CV patients, spotting feedback from patients and newspapers regarding drugs, therapeutic procedures, or medical devices and the integration of SA modules in new technological concepts for monitoring CV patients. Each of these topics is discussed below in an attempt to synthesize the current literature on SA in cardiovascular diseases, right after introducing the reader to basic concepts regarding medical SA and justifying how SA can contribute to increasing quality in cardiovascular healthcare.

MEDICAL SENTIMENT ANALYSIS—INTRODUCTORY CONCEPTS

What Is SA in Medicine?

Medical SA is the field of study that analyzes patients' and doctors' opinions, sentiments, attitudes, and emotions toward various clinical contexts (treatment side-effects, medical diagnosis concerns, emotional consequences of illness, emotional context during the onset or evolution of a specific disease, patient-physician relationship, physician attitudes in clinical notes) expressed in written text (20). While traditional AI deals with facts and logical, objective data analysis, sentiment research refers to opinions—correctly identifying subjective emotional communication.

Several medical entities associable with sentiments have been defined: health status (improved/worsened, good/bad), medical condition (improved/worsened), diagnosis (certain/uncertain/preliminary), medical procedure (positive/negative outcome), medication (helpful/useless/adverse events) (20).

Sentiment Classification

Sentiment classification comprises two comprehensive categories: lexicon-based and ML/NLP-based classifications (21). The classifiers build upon sentiment lexicons (i.e., a collection of polar or opinion words, associated with their sentiment polarity, that is, positive or negative) are lexicon-based (or rule-based classifiers). Sentiment lexicons are produced manually or semiautomatically (22) and regularly stored as dictionaries. Conversely, ML/NLP-based classifiers are built using training datasets or annotated data collections.

Types of SA

Some of the most popular types of SA are: fine-grained SA, emotion detection, aspect-based SA and multilingual SA (23). Fine-grained SA considers an expanded number of polarity categories (e.g., very positive / positive / neutral / negative / very negative). Emotion detection uses lexicons or ML/NLP systems to detect sentiments. Aspect-based SA highlights which particular aspects or features people are mentioning in a positive, neutral, or negative way (23). Multilingual SA techniques

TABLE 1 | Characteristics of the included studies reporting SA solutions for cardiovascular diseases research.

Authors	Objectives	Data sources	SA methods	Results
1. Detecting emotional risk factors for CVD				
Eichstaedt et al., (9)	Analyze social-media language to identify community-level psychological correlates of age-adjusted mortality from AHD	Data from 1,347 US counties for which AHD mortality rates, health variables, and 50,000 tweeted words were available	Cross-sectional regression model based on Twitter language	Negativity emerged as significant risk factor (partial rs = 0.06, 95% confidence interval, or CI = [0.00, 0.11], to 0.12, 95% CI = [0.07, 0.17]) for CAD mortality
Hemalatha et al., (10)	Identify relevant MI risk factors using Twitter data	Twitter users with a MI history	LR for positive/negative emotion classification, with words weighted using TF.IDF	Not available
Medina Sada et al., (11)	Identify the relation between the sentiment of tweets and CVD	Tweets in the counties along Interstate 20 in Texas	Naïve Bayes, Multinomial Naïve Bayes, Bernoulli Naïve Bayes, Support Vector, and Linear Support Vector	High positive-to-negative ratio and positive-to-population ratio tend to associate with counties with low CVD rate
2. Detecting positive/negative attitudes of CV patients toward their disease				
Verma et al., (12)	Assess public health impact of CVD and patients' adherence and attitudes toward the disease	Tweets in english related to CVD	Not specified	The percentage of positive tweets are 45%, neutral tweets are 30 and 25% are negative tweets
Pimenta et al., (13)	Identify which fitness and nutrition apps that support behavior change (which could reduce CVD mortality) elicits a positive response from the users	User store reviews of a sample of fitness and nutrition apps	Text mining with Sketch Engine online app	StepsApp pedometer had the highest percentage of positive tags while VeryFitPro had the lowest
3. Detection of cardiac arrhythmia				
Behadada et al., (14)	Provides insights into arrhythmia detections from big data information sources	Expert knowledge, data and textual information from Pubmed articles and MIT-BIH database	Semi-automatically fuzzy partition rules and grammar-based text extraction SA	Accuracy of 93% and a high level of interpretability of 0.646 for the detection of cardiac arrhythmia
4. Triage of CV patients				
Lowres et al., (15)	Assessing the feasibility of using an ML program to triage incoming SMS text messaging replies as requiring health professional review or not	3,118 SMS text messaging replies received from 2 clinical trials	Naïve Bayes, OneVsRest, Random Forest Decision Trees, Gradient Boosted Trees, Multilayer Perceptron	The multilayer perceptron model achieved the highest accuracy (AUC 0.86)
5. Feedbacks from patients and newspapers: reviews on drugs, therapeutic procedures, or medical devices				
Pérez et al., (16)	Identify opinions on the drugs prescribed for chronic-degenerative diseases (including hypertension medication)	Blogs and specialized websites in the Spanish language	Hybrid approach (supervised machine learning and use of semantics through a tagged corpus)	The analysis of the sentiments of the opinions on the prescribed drugs is successful and reduces time and effort
Austin et al., (17)	Understand patients' attitudes toward LVAD therapy	Posts, comments, and titles from MyLVAD.com	Lexicon-based SA	Positive sentiment words are the most frequent. In comparison to other LVAD complications, "infection" is mentioned disproportionately more times.
Emerging Markets, (18)	Assess whether Biotricity (health tech company targeting mainly chronic CVDs) trends positively or not in the media	News media	InfoTrie Financial SA Solutions	Biotricity has been trending positively, achieving a news buzz score of 10 out of 10, with a market sentiment score of 4.0
6. SA modules integrated in new technological concepts for monitoring CV patients				
Sharma et al., (19)	Propose a smart conceptual framework for monitoring patients with CV or diabetes	Social media and other online resources (for the SA component)	Hybrid system merging SA techniques, data mining, ML, IoT, bio-sensors, chatbots, contextual entity search, granular computing	Not available

*Cardiovascular disease (CVD); Atherosclerotic heart disease (AHD); United States (US); Coronary arteries diseases (CAD); Myocardial infarction (MI); Logistic regression (LR); Term Frequency * Inverse document frequency (TF.IDF); Left ventricular assist device (LVAD); Machine Learning (ML); Internet of Things (IoT).*

have been developed in order to analyses data in different languages (24).

The introductory concepts in medical SA are summarized in **Figure 1**.

JUSTIFYING THE NEED TO INTEGRATE MODERN SENTIMENT ANALYSIS SOLUTIONS IN CARDIOLOGY: HOW SENTIMENT ANALYSIS CAN CONTRIBUTE TO INCREASING QUALITY IN CARDIOVASCULAR HEALTHCARE

CVD and emotional disorders seem to influence each other in a bidirectional manner (25). Coronary arteries diseases (CAD) and their impact in triggering emotional disorders is well documented. Moreover, emotional disturbances have the power to induce or worsen existing coronary artery diseases (25). Emotional disturbances were reported as potent cardiovascular (CV) risk factors (25).

There is a need to integrate the assessment of the emotional status in the cardiovascular risk prediction, a desideratum long considered unattainable due to a high degree of subjectivity regarding human sentiments and insufficient technical developments (25). The considerable technological and AI progress provides the opportunity to start developing strategies for building solutions capable of systematically assessing emotions. Since patients express their thoughts and feelings more openly in online than ever before (26), SA is becoming an essential tool to monitor and understand these sentiments and provide predictive models (27).

The increasing popularity of social platforms and discussion forums enabling the collection of unlimited amounts of written text and opinions, creates a favorable ground for testing novel SA methods. A descriptive study identified 4.9 million Tweets about CVD having common topics such as risk factors, awareness, and management of CVD (28). Using the vast amount of Twitter data on CVD, a study predicted county-level heart disease mortality based on the assessment of psychological language in Twitter posts (9). Given the SA superiority over standard predictive models (29), SA integration would lead to higher performance models and more complex CV predictions.

An obstacle to further improvement of AI/ML models is that 90% of the world's data is unstructured (30). While exam results are reported in a structured way, observations, intuitions, opinions, and experiences are communicated in an unstructured manner throughout clinical records, notes or online. Unstructured data is extremely time-consuming to analyses and it is unusable by the standard AI/ML solutions. This represents a missed opportunity for understanding patients' experience in an increasingly "connected" world. Thereby, SA and its ability to systematically review unstructured data is ready to overrun old limitations and produce higher-quality results.

In addition to these major benefits, several other perquisites have been highlighted in the literature. Firstly, data mining and SA may be used to explore the issues surrounding controversial research subjects, guidelines' changes or new recommendations in CV medicine (31).

Secondly, according to the Information Strategy for the National Health Service (NHS) in England, SA may be valuable for patients in facilitating choice of hospitals (32) by predicting, from free-text, "*a reasonably accurate assessment of patients' opinion about different performance aspects of a hospital*" (27).

Thirdly, online public testimonies carry classical indicators (such as self-reported quality of life indicators during and post treatment) and other relevant indicators (such as attitudes toward political legislation, loss of healthcare coverage, raising support, spreading awareness) that are difficult to capture by conventional means of self-reporting. Social listening can provide valuable feedback from patients and can help healthcare professionals and regulators to personalize and improve treatment regimens and improve public health surveillance strategies (33).

A SYNTHESIS OF THE CURRENT LITERATURE ON SA IN CARDIOVASCULAR DISEASES

Emotional Risk Factors for CVD

Poor emotion regulation was associated with CV risk in several studies (34, 35). Moreover, educational programs aimed at improving emotion regulation strategies among patients in cardiac rehabilitation proved to be feasible (36).

Whereas emotion regulation is a teachable skill that may play a role in preventing CVD, emotions must first be systematically recognized and documented before deciding whether the intervention of educational programs is appropriate. Several models of emotional recognition, capable of ensuring a systematic evaluation of sentiments, have been proposed based on eye-tracking (37–39), heart sound signals (40), cardiovascular response in daily life using the k-Nearest-Neighbor classifier (41), heart rate data collected from wearable devices (42), or even computational evaluation of facial expressions (43).

The Twitter platform was used on a large scale to assess the psychological language as a risk factor for atherosclerotic CAD by applying SA analysis (9). Hostility and chronic stress are known risk factors for CVD (44). All language patterns highlighting negative psychological traits (anger, negative-relationship, negative-emotion, and disengagement) emerged as significant risk factors [partial rs = 0.06, 95% confidence interval, or CI = (0.00, 0.11), to 0.12, 95% CI = (0.07,0.17)] for CAD mortality while the use of engagement words [$r = -0.09$, 95% CI = (-0.14, -0.04)] and positive-emotion words [partial $r =$ –.05, 95% CI = (–.00, –.11)] appeared significantly protective. Surprisingly, a regression model "*based only on Twitter language*" predicts CAD mortality significantly better than a model with 10 common demographic, socioeconomic, and health risk factors (e.g., smoking, diabetes, hypertension, and obesity) (9).

A SA/ML methodology has been proposed to identify the relevant myocardial infarction (MI) emotional risk factors using

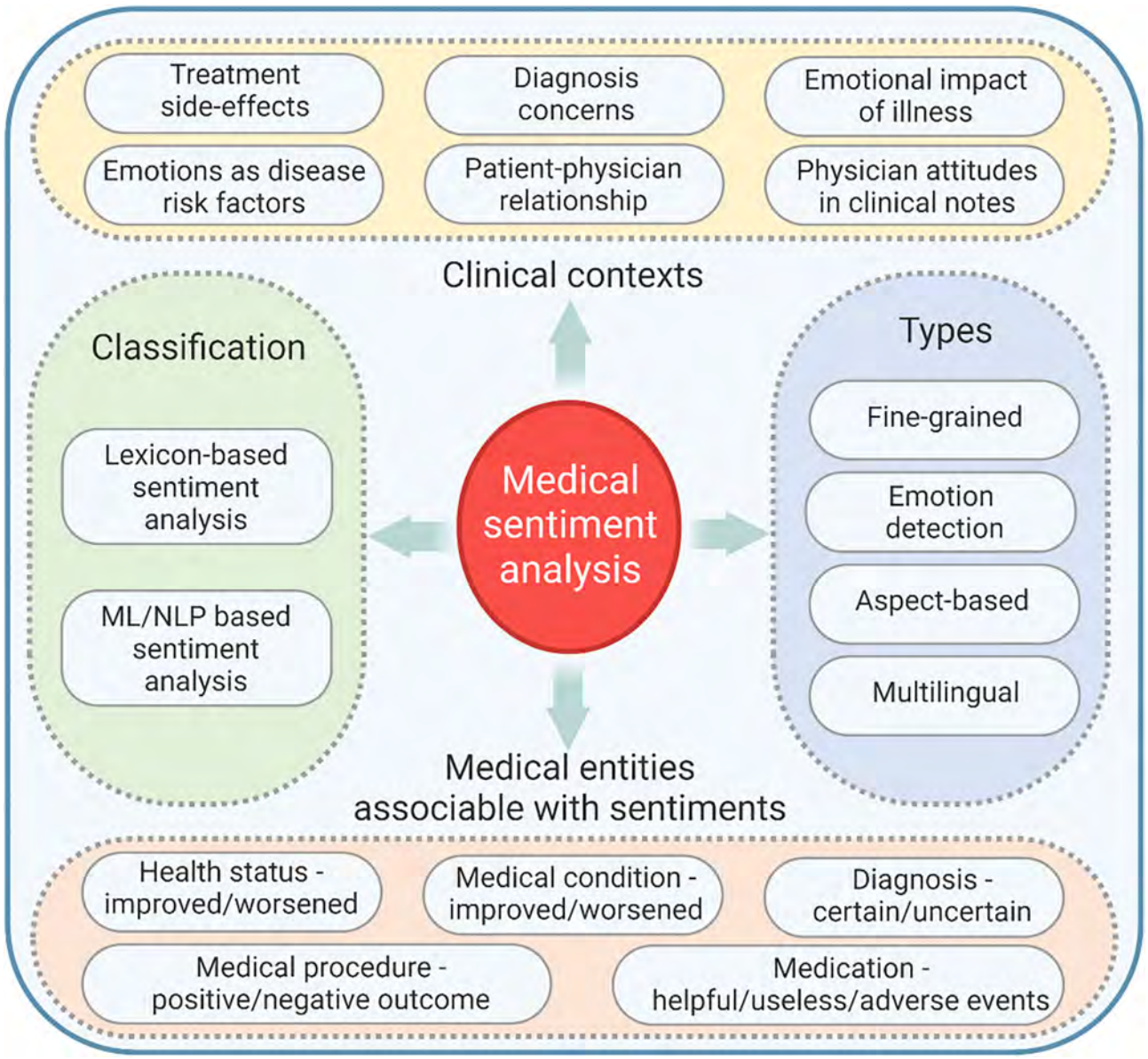

FIGURE 1 | Introductory concepts in medical SA: applicable clinical contexts, medical entities associable with sentiments, classification, and types of SA.

Twitter data (10). Even if it seems unbelievable, the authors explore the possibility of screening tweets for MI risk factors as a tool to be used in preventive medicine. However, no results are yet provided.

Acute MI was repeatedly studied as an important consequence of stressful social disasters and social stress [e.g., the influence on MI of the death of a beloved (45), earthquakes (46), or war (47)]. In this context, a Korean team used the SA/ML algorithm of Semantria Lexalytics and managed to prove the effects of the Sewol Ferry Disaster on social stress by examining data from the top social media platforms used worldwide (YouTube, Twitter, and Facebook) (45).

Another way to harness the capabilities of SA was to analyze tweets in an attempt to find the relation between the sentiment of tweets and CVD in the counties along Interstate 20 in Texas (11). The sentiment of tweets from each region was determined by five classifiers (Naïve Bayes, Multinomial Naïve Bayes, Bernoulli Naïve Bayes, Support Vector, and Linear Support Vector) and was compared with the regional CVD rates. The Positive-to-Population rate is related to the CVD data map and Negative-to-Population rates have inverse relations to the CVD data map. This descriptive study highlights the potential of SA in epidemiological research, generating causal hypotheses and finding trends of diseases.

Detecting Positive/Negative Attitudes of CV Patients Toward Their Disease in Order to Identify Strategies for Bettering Attitudes and Behaviors

Patients' attitude toward their disease may be an important drive for treatment adherence and a significant buffer of the impact of illness (48). However, the prevalence of positive attitudes toward the disease may often be low (49). SA is capable of contributing with systematized analysis and information on subjective attitudes (where traditional healthcare management is not able), fine-tuning deeper preventive strategies.

A method using SA was built to understand public health impact of CVD and patients' attitudes toward the disease in order to develop personalized therapeutic strategies depending on patients' adherence (12). Less than half of the tweets on CVD (45%) were found positive raising awareness on the importance of positive behavior change.

Addressing Behavioral change interventions could drastically reduce overall mortality from CVD (13). Behavior Change Techniques Taxonomy version 1 (BCTTv1) was applied to a sample of fitness and nutrition mobile apps and SA was used to identify which apps that support behavior change elicits a positive response from the users (13). StepsApp Pedometer had the highest percentage of positive tags while VeryFitPro had the lowest.

Various types of SA tools were used to examine the impact and improvement in diseases such as CVD, as SA contributes in designing strategies to improve patients understanding and behavior (50).

Detection of Cardiac Arrhythmia

Computers can be trained to learn as humans do. Behadada et al. (14) proved that computers, as students, can learn from experts, textual data (scientific articles) and experience (experiments data). The authors introduced a novel method to define semi-automatically fuzzy partition rules to provide a powerful and accurate insight into the detection of cardiac arrhythmia. Fuzzy logic allows merging three completely different sources of knowledge by learning to define and integrate rule bases. The expert is invited to express his/her knowledge through linguistic (expert) rules. Moreover, the rules induced from data are called induced rules. Finally, the automated extraction of fuzzy partition rules from Pubmed articles identifies relevant arrhythmia insights and intuitions (mood described by text fragments) through grammar-based text extraction and SA. All extracted rules are merged into a unique knowledge base resulting in the definition of a common universe for the different knowledge domains. The evaluation carried out showed an accuracy rate of 93% and a high level of interpretability of 0.646 for the detection of cardiac arrhythmia.

Compared to the traditional ML solutions, besides an excellent accuracy, the approach proposed by Behadada et al. (14) comes with the major advantage of a high interpretability, as the computer is able to highlight all knowledge rules that led to a certain result.

Triage of CV Patients

In a cardiovascular secondary prevention setting, the feasibility of using an ML program to triage and classify incoming SMS text messaging replies as requiring health professional review or not, was assessed and reported (15). The SMS messaging programs are a cost-efficient way for patients monitored in secondary prevention centers to regularly report their health status. However, the additional staff required to monitor and moderate the patients' SMS text messaging replies may negatively impact the cost-effectiveness of the SMS-based system. In order to reduce these costs, Lowres et al. (15) proposed five ML models (Naïve Bayes, OneVsRest, Random Forest Decision Trees, Gradient Boosted Trees, and Multilayer Perceptron) and an ensemble model for the automatic triaging of SMS replies. The Multilayer Perceptron model achieved the highest accuracy (AUC 0.86; 4.85% false negatives; and 4.63% false positives). After future validations against larger datasets, the authors are optimistic that the ML solution will significantly reduce staff workload.

Feedbacks From Patients and Newspapers: Reviews on Drugs, Therapeutic Procedures, or Medical Devices

Medication and medical devices reviews are important to improve their quality, safety, adherence and use (51). Side effects may influence patients' adherence, thus pharmacovigilance is a key strategy to improve adherence (51).

The "SentiScrap" system applies SA through a hybrid approach (supervised machine learning and use of semantics through a tagged corpus) to identify opinions, comments, and polarity of the drugs prescribed for chronic-degenerative diseases (including hypertension medication), available in blogs and specialized websites in the Spanish language (16). Such a solution is of great help to health specialists as it reduces the time and effort to systematically search for patients' opinions, comments and experiences regarding the use of drugs, facilitating clinical decision making.

Medical devices' reviews were also considered for sentiment assessment. A lexicon-based SA was performed to pool together patients' experiences (fears, opinions, thoughts) from MyLVAD.com regarding their implanted left ventricular assist device (LVAD) (17). The results of the analysis indicate dominant positive sentiment {a net sentiment ratio [(number of positive words—number of negative words)/(number of total words)] of 2.1%} and a common use of the word "infection" (208 mentions) compared to other words denoting complications such as "stroke" (29 mentions), "bleeding" (30 mentions), and "thrombosis" or "clot" (32 mentions). This type of analysis might help to elucidate hidden, subjective segments of patients' health which factor into the objective measures of health.

Biotricity Inc. is a medical diagnostic and consumer healthcare tech company that is a leading producer of remote medical monitoring devices. Biotricity's main targets are chronic CVDs. With the help of the analytics firm InfoTrie Financial Solutions' Sentiment Analysis it was proved that Biotricity has been

trending positively in the media, achieving a news buzz score of 10 out of 10, with a market sentiment score of 4.0 (18).

SA Modules Integrated in New Technological Concepts for Monitoring CV Patients

A smart conceptual framework for monitoring patients with CV or diabetes was proposed (19). The concept respresents a hybrid healthcare system designed to merge distinct emerging computing techniques such as data mining, ML, Internet of Things (IoT), bio-sensors, SA, chatbots, contextual entity search, and granular computing. Bio-sensors and IoT are used for the continuous monitoring of the patient's health parameters and emergency notifications. SA is intended to mine social media and other online resources in order to keep the patient and the healthcare professional up to date regarding CV and diabetes updated informations. Data mining and ML are used for patient classification, diagnosis, and health predictions. This hybrid AI and smart framework may provide an effective and economical solution to CV and diabetes patients by minimizing various implicit and explicit medical expenses, optimizing the use of vital medical resources and manpower, and further enhancing the patient care.

CHALLENGES AND OBSTACLES OF SENTIMENT ANALYSIS IN CARDIOVASCULAR HEALTH

SA is indeed a promising field that can add valuable insights to the traditional and objective measures of health and contribute to clinical decision making. However, SA is the hardest task in NLP as analyzing sentiments in an accurate manner is a difficult task even for humans.

Context and meaning play a crucial role in interpreting emotions. For instance, this Twitter post: "*Safe to say she may have been shocked to hear that the research does not suggest that high colesterol is a risk factor for heart disease*" was automatically classed as negative by an automated SA algorithm, due to the potentially negative concepts such as "shocked", "high cholesterol", "risk factor" and "heart disease" (52). However, the actual meaning is positive as the author is referring to the positive fact that the cited research does not incriminate negative associations. A major and mandatory challenge to SA techniques is to be able to integrate context (such as cultural, medical, political, legal, economic) and meaning. Moreover, in some cases, it is necessary to know much more than emotional polarity. For real life impact, SA algorithms should be equipped with the ability to categorize and organize subjective information, detect irony and sarcasm, comparisons, and emojis.

In general, the measure of how well humans annotators can decide on the same labels (inter-annotator agreement) is low when it comes to SA (53). Since machines learns from the data they are fed, SA models might not be as accurate as other types of classifiers. This challenge may be overcome after developing more rigorous definitions of emotional polarity and neutrality.

Another aspect to consider is that only 10% of individuals between the ages of 50–64 use social media sites such as Twitter (54). This limitation is worthy of consideration until social media platforms will become more popular among older patients.

One further obstacle is represented by the ethical implications of utilizing online publically available data from social media platforms for research purposes (55). Current regulations do not yet fully consider this aspect, although this is probably just a matter of time until ethical implications will be rigorously addressed and clarified.

CONCLUSIONS

This paper introduced the readers to basic concepts surrounding medical SA and justified how SA can contribute to increasing quality in cardiovascular healthcare, emphasizing the need to invest more research into this new, promising and challenging domain. Our synthesis of the current literature on SA in CVDs proves its clinical potential. It also shows that the domain is only at the beginning. Many other clinical utilities, such as the assessment of emotional consequences of illness, patient-physician relationship, physician intuitions in CVD are not yet explored. These remain important research directions for the future, along with proposing detailed regulations for ethical implications, popularizing health social media and online expression among elders, developing more insightful definitions of emotional polarity and neutrality, and investing research into the discovery of powerful SA algorithms that are able to integrate global context and meaning.

AUTHOR CONTRIBUTIONS

ABu and ABr: conceptualization. ABu and IP: methodology and writing—review and editing. ABr, ABu, IP, MA, and OG: resources and writing—original draft preparation. ABr, OG, and MA: supervision. All authors have read and agreed to the published version of the manuscript.

REFERENCES

1. Ligthart A, Catal C, Tekinerdogan B. Systematic reviews in sentiment analysis: a tertiary study. *Artif Intell Rev.* (2021) 54:4997–5053. doi: 10.1007/s10462-021-09973-3
2. Briganti G, Le Moine O. Artificial intelligence in medicine: today and tomorrow. *Front Med.* (2020) 7:27. doi: 10.3389/fmed.2020.00027
3. Ghassemi MM, Al-Hanai T, Raffa JD, Mark RG, Nemati S, Chokshi FH. How is the doctor feeling? ICU provider sentiment is associated with diagnostic imaging utilization. *Annu Int Conf IEEE Eng Med Biol Soc.* (2018) 2018:4058–64. doi: 10.1109/EMBC.2018.8513325
4. Gohil S, Vuik S, Darzi A. Sentiment analysis of health care tweets: review of the methods used. *JMIR Public Health Surveill.* (2018) 4:e43–43. doi: 10.2196/publichealth.5789
5. WHO. Cardiovascular diseases (CVDs). WHO (2021). Available online at: https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds) (accessed January 15, 2022).

6. Eberly LA, Khatana SAM, Nathan AS, Snider C, Julien HM, Deleener ME, Adusumalli S, Telemedicine outpatient cardiovascular care during the COVID-19 pandemic. (2020) 142:510–2. doi: 10.1161/CIRCULATIONAHA.120.048185
7. Korkontzelos I, Nikfarjam A, Shardlow M, Sarker A, Ananiadou S, Gonzalez GH. Analysis of the effect of sentiment analysis on extracting adverse drug reactions from tweets and forum posts. *J Biomed Inform.* (2016) 62:148–58. doi: 10.1016/j.jbi.2016.06.007
8. Nikfarjam A, Sarker A, O'Connor K, Ginn R, Gonzalez G. Pharmacovigilance from social media: mining adverse drug reaction mentions using sequence labeling with word embedding cluster features. *J Am Med Inform Assoc.* (2015) 22:671–81. doi: 10.1093/jamia/ocu041
9. Eichstaedt JC, Schwartz HA, Kern ML, Park G, Labarthe DR, Merchant RM. et al. Psychological language on twitter predicts county-level heart disease mortality. *Front Psychol.* (2015) 26:159–69. doi: 10.1177/0956797614557867
10. Hemalatha R, Monicka M. Sentiment analysis on myocardial infarction using tweets data. *Int J Comput Sci Technol.* (2018) 9:61–5. Available online at: http://www.ijcst.com/vol9/issue4/12-m-b-monicka.pdf
11. Medina Sada D, Mengel S, Gittner LS, Khan H, Rodriguez MAP, Vadapalli R. A preliminary investigation with twitter to augment cvd exposome research. In: *Proceedings of the Fourth IEEE/ACM International Conference on Big Data Computing, Applications and Technologies.* New York, NY: Association for Computing Machinery (2017). p. 169–78. Available online at: https://dl.acm.org/doi/pdf/10.1145/3148055.3148074
12. Verma L, Sapra V. Semantic analysis of cardiovascular disease sentiment in online social media. In: *Proceedings of International Conference on Advancements in Computing & Management (ICACM)* (2019). Available online at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3462426
13. Pimenta F, Lopes L, Gonçalves F, Campos P. Designing positive behavior change experiences: a systematic review and sentiment analysis based on online user reviews of fitness and nutrition mobile applications. In: *19th International Conference on Mobile and Ubiquitous Multimedia.* New York, NY: Association for Computing Machinery (2020). p. 152–61. Available online at: https://dl.acm.org/doi/10.1145/3428361.3428403
14. Behadada O, Trovati M, Chikh MA, Bessis N. Big data-based extraction of fuzzy partition rules for heart arrhythmia detection: a semi-automated approach. *Concurrency Comput Pract Exp.* (2016) 28:360–73. doi: 10.1002/cpe.3428
15. Lowres N, Duckworth A, Redfern J, Thiagalingam A, Chow CK. Use of a machine learning program to correctly triage incoming text messaging replies from a cardiovascular text–based secondary prevention program: feasibility study. *JMIR Mhealth Uhealth.* (2020) 8:e19200. doi: 10.2196/19200
16. Pérez KC, Sánchez-Cervantes JL. del Pilar Salas-Zárate M, LÁR Hernández, L Rodríguez-Mazahua A. Sentiment analysis approach for drug reviews in Spanish *Res Comput Sci.* (2020) 149:43–51.
17. Austin MA, Saxena A, O'Malley TJ, Maynes EJ, Moncure H, Ott N, et al. et al. Computational sentiment analysis of an online left ventricular assist device support forum: positivity predominates. *Ann Cardiothorac Surg.* (2020) 10:375–82. doi: 10.21037/acs-2020-cfmcs-fs-11
18. Markets E. *Emerging Markets Report: What's the Big Buzz on Biotricity?* (2020). Available online at: https://www.globenewswire.com/news-release/2020/02/10/1982225/0/en/Emerging-Markets-Report-What-s-the-Big-Buzz-on-Biotricity.html (accessed January 15, 2022).
19. Sharma M, Singh G, Singh R. An advanced conceptual diagnostic healthcare framework for diabetes and cardiovascular disorders. arXiv preprint arXiv:1901.10530 (2019). doi: 10.4108/eai.19-6-2018.154828
20. Denecke K, Deng Y. Sentiment analysis in medical settings: new opportunities and challenges. *Artif Intell Med.* (2015) 64:17–27. doi: 10.1016/j.artmed.2015.03.006
21. Kaity M, Balakrishnan V. Sentiment lexicons and non-english languages: a survey. *Knowl Inf Syst.* (2020) 62:4445–80. doi: 10.1007/s10115-020-01497-6
22. Lo SL, Cambria E, Chiong R, Cornforth D. Multilingual sentiment analysis: from formal to informal and scarce resource languages. *Artif Intell Rev.* (2017) 48:499–527. doi: 10.1007/s10462-016-9508-4
23. Aqlan AAQ, Manjula B, Lakshman Naik R. *A Study of Sentiment Analysis: Concepts, Techniques, and Challenges.* Singapore: Springer Singapore (2019). p. 147–62.
24. Boiy E, Moens M-F. A machine learning approach to sentiment analysis in multilingual web texts. *Inf Retr Boston.* (2009) 12:526–58. doi: 10.1007/s10791-008-9070-z
25. Tennant C, McLean L. The impact of emotions on coronary heart disease risk. *J Cardiovasc Risk.* (2001) 8:175–83. doi: 10.1177/174182670100800309
26. Settanni M, Marengo D. Sharing feelings online: studying emotional well-being via automated text analysis of facebook posts. *Front Psychol.* (2015) 6:1045. doi: 10.3389/fpsyg.2015.01045
27. Greaves F, Ramirez-Cano D, Millett C, Darzi A, Donaldson L. Use of sentiment analysis for capturing patient experience from free-text comments posted online. *J Med Internet Res.* (2013) 15:e239. doi: 10.2196/jmir.2721
28. Sinnenberg L, DiSilvestro CL, Mancheno C, Dailey K, Tufts C, Buttenheim AM. et al. Twitter as a potential data source for cardiovascular disease research. *JAMA Cardiol.* (2016) 1:1032–6. doi: 10.1001/jamacardio.2016.3029
29. Medhat W, Hassan A, Korashy H. Sentiment analysis algorithms and applications: a survey. *Ain Shams Eng J.* (2014) 5:1093–113. doi: 10.1016/j.asej.2014.04.011
30. Wang G, Xie M, Ma J, Guan J, Song Y, Wen Y, et al. Is co-infection with influenza virus a protective factor of COVID-19? *SSRN Electronic J.* (2020). doi: 10.2139/ssrn.3576904
31. Gouda P, Das D, Clark A, Ezekowitz JA. The impact and implications of twitter for cardiovascular medicine. *J Card Fail.* (2017) 23:266–7. doi: 10.1016/j.cardfail.2016.12.005
32. Health DO. *The Power of Information: Putting All of Us in Control of the Health and Care Information We Need.* London: Department of Health (2012).
33. Clark EM. *Applications in Sentiment Analysis and Machine Learning for Identifying Public Health Variables Across Social Media.* The University of Vermont and State Agricultural College, Burlington, United States (2019). Available online at: https://scholarworks.uvm.edu/graddis/1006/
34. Roy B, Riley C, Sinha R. Emotion regulation moderates the association between chronic stress and cardiovascular disease risk in humans: a cross-sectional study. *Stress.* (2018) 21:548–55. doi: 10.1080/10253890.2018.1490724
35. Besharat MA, Ramesh S. The relationship between worry and anger rumination with adjustment problems to heart disease: The mediating role of difficulties in emotion regulation. *Heart and Mind.* (2017) 1:141. doi: 10.4103/hm.hm_7_18
36. Wierenga KL, Fresco DM, Alder M, Moore SM. Feasibility of an emotion regulation intervention for patients in cardiac rehabilitation. *West J Nurs Res.* (2021) 43:338–46. doi: 10.1177/0193945920949959
37. Lim JZ, Mountstephens J, Teo J. Emotion recognition using eye-tracking: taxonomy, review and current challenges. *Sensors.* (2020) 20:2384. doi: 10.3390/s20082384
38. Tarnowski P, Kołodziej M, Majkowski A, Rak RJ. Eye-Tracking Analysis for Emotion Recognition. *Comput Intell Neurosci.* (2020) 2020:2909267. doi: 10.1155/2020/2909267
39. Schurgin M, Nelson J, Iida S, Ohira H, Chiao J, Franconeri S. Eye movements during emotion recognition in faces. *J Vis.* (2014) 14:14–14. doi: 10.1167/14.13.14
40. Xiefeng C, Wang Y, Dai S, Zhao P, Liu Q. Heart sound signals can be used for emotion recognition. *Sci Rep.* (2019) 9:6486. doi: 10.1038/s41598-019-42826-2
41. Jo Y, Lee H, Cho A, Whang M. *Emotion Recognition Through Cardiovascular Response in Daily Life Using KNN Classifier.* Singapore: Springer Singapore (2018). p. 1451–6.
42. Shu L, Yu Y, Chen W, Hua H, Li Q, Jin J. et al. Wearable emotion recognition using heart rate data from a smart bracelet. *Sensors.* (2020) 20:718. doi: 10.3390/s20030718
43. Tarnowski P, Kołodziej M, Majkowski A, Rak RJ. Emotion recognition using facial expressions. *Procedia Comput Sci.* (2017) 108:1175–84. doi: 10.1016/j.procs.2017.05.025
44. Menezes AR, Lavie CJ, Milani RV, O'Keefe J, Lavie TJ. Psychological risk factors and cardiovascular disease: is it all in your head? *Postgrad Med.* (2011) 123:165–76. doi: 10.3810/pgm.2011.09.2472
45. Mostofsky E, Maclure M, Sherwood JB, Tofler GH, Muller JE, Mittleman MA. Risk of acute myocardial infarction after the death of a significant person in one's life: the determinants of myocardial infarction onset study.

Circulation. (2012) 125:491–6. doi: 10.1161/CIRCULATIONAHA.111.061770
46. Suzuki S, Sakamoto S, Koide M, Fujita H, Sakuramoto H, Kuroda T, et al. Hanshin-Awaji earthquake as a trigger for acute myocardial infarction. *Am Heart J*. (1997) 134:974–7. doi: 10.1016/S0002-8703(97)80023-3
47. Kim YH, Her AY, Rha SW, Choi BG, Shim M, Choi SY. et al. Routine angiographic follow-up versus clinical follow-up after percutaneous coronary intervention in acute myocardial infarction yonsei. *Med J*. (2017) 58:720–30. doi: 10.3349/ymj.2017.58.4.720
48. Dushad R, Mintu M, Samaksha PB, Basavana GH. A study of drug attitude and medication adherence and its relationship with the impact of illness among the mentally ill. *Arc Clin Psychiatr*. (2019) 46:85–8. doi: 10.1590/0101-60830000000201
49. Assunção SC, Fonseca AP, Silveira MF, Caldeira AP, Pinho LD. Knowledge and attitude of patients with diabetes mellitus in primary health care. *Escola Anna Nery*. (2017) 21. doi: 10.1590/2177-9465-ean-2017-0208
50. Bhoi D, Thakkar A. 12. Impact of sentiment analysis tools to improve patients' life in critical diseases. In: Srivastava R, Mallick PK, Rautaray SS, Pandey M, editors. *Computational Intelligence for Machine Learning and Healthcare Informatics*. Berlin; Boston, MA: De Gruyter (2020). p. 239–52. Available online at: https://www.degruyter.com/document/doi/10.1515/9783110648195-012/html
51. Blenkinsopp A, Bond C, Raynor DK. Medication reviews. *Br J Clin Pharmacol*. (2012) 74:573–80. doi: 10.1111/j.1365-2125.2012.04331.x
52. Kennedy K. *Does Automated Sentiment Analysis Work for Studying Healthcare Conversation?* Creation Knowledge (2015). Available online at: https://creation.co/knowledge/automated-sentiment-analysis-healthcare-conversation/
53. Bobicev V, Sokolova M. *Inter-annotator agreement in sentiment analysis: machine learning perspective*. In: *Proceedings of the International Conference Recent Advances in Natural Language Processing, RANLP 2017*. Varna: Incoma Ltd (2017). p. 97–102. Available online at: https://www.acl-bg.org/proceedings/2017/RANLP%202017/pdf/RANLP015.pdf
54. Duggan M, Brenner J. *The Demographics of Social Media Users, 2012*. Washington, DC: Pew Research Center's Internet & American Life Project (2013).
55. Gouda P, Das D, Clark A, Ezekowitz JA. The impact and implications of twitter for cardiovascular medicine. *J Card Fail*. (2016) 23:266–7. Available online at: https://www.onlinejcf.com/article/S1071-9164(16)31242-8/fulltext

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Review

Perforated Plate for Ballistic Protection—A Review

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Abstract: In recent years, the interest of the scientific community in perforated plates for ballistic protection has increased. Perforated plates do not represent protection by themselves, rather, they are used in the armour systems of armoured vehicles, in conjunction with base armour, since they are intended to induce bend stresses, where a penetrating core fracture occurs. The fragments are subsequently stopped by base armoured vehicle armour. Although for the first time used several decades ago, perforated plates are found to be attractive even today. The main reason is the combination of very convenient properties. Besides high mass effectiveness, they possess a high multi-impact resistance, since their perforations arrest cracks. Therefore, a relatively wide array of materials is suitable for perforated plate fabrication, ranging from alloy steel to some types of cast iron. Being made of metallic materials, raw material costs are relatively low compared to ceramics or composite materials, making them very attractive for present and future armoured vehicles. Finally, armour system consisting of a perforated plate and base plate at some distance, reduce the effectiveness of both shaped charge jets and act as blast mitigators.

Keywords: armour protection; perforated plates; ballistic behavior; blast mitigation

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1. Introduction

Passive armour is aimed to withstand the impact of projectiles (shrapnel, bullets, missiles) and thus to protect represents the most important means of protecting the personnel and vehicle subsystems from enemy fire. There is a wide array of materials and configurations that can effectively be used as passive armour protection, Figure 1 [1,2]. Armour steel and aluminium alloys are structural materials and are usually supplemented by other types of armour, to facilitate a relatively high mass effectiveness. Moreover, typically ceramics, or metal matrix composites, represent a parasitic mass, that stresses the structural steel or aluminium alloy's body of the vehicle [3–5]. Mass effectiveness (Em) is the ratio of the areal density of a reference armour (usually rolled homogenous armour—RHA) to the areal density of experimental armour [6]. Table 1, there are examples of armour materials and descriptive configurations with their thicknesses, areal densities and mass effectiveness.

Perforated plates represent a non-homogenous armour, usually employed as applique, or add-on armour of various armoured vehicles. They appear in predominantly light armoured vehicles, the widest type of armoured vehicles used. The application of non-homogenous vehicle armour dates back to World War II, when the German Schuerzen wire mesh appeared on a number of PzKpfw IV Ausf J [8] medium tanks. Thoma Schuerzen was initially added to provide increased protection against kinetic energy rounds fired from the Soviet 14.5 mm anti-tank rifles, but during its application, it also proved very effective against American M6 Bazooka-shaped charge anti-tank rocket launchers. Furthermore, its most important feature was its lightweight nature. It was approximately three times lighter than the admittedly more common Schuerzen homogenous mild steel spaced plates used

on PzKpfw IV Ausf G and H from 1943. Instead of 8 mm mild steel plates in Schuerzen, a lighter mesh, made of 5.5 mm diameter mild steel wires at around 19 mm distance between wire axes was applied in Thoma Schuerzen. The main mechanism in both Schuerzen and Thoma Schuerzen was the induction of yaw in the projectile penetrating core, so base armour can provide full protection [9,10]. A lower stiffness of Thoma Schuerzen compared to Schuerzen was compensated by its non-homogenous structure, more effective in inducing yaw, and particularly, weight savings.

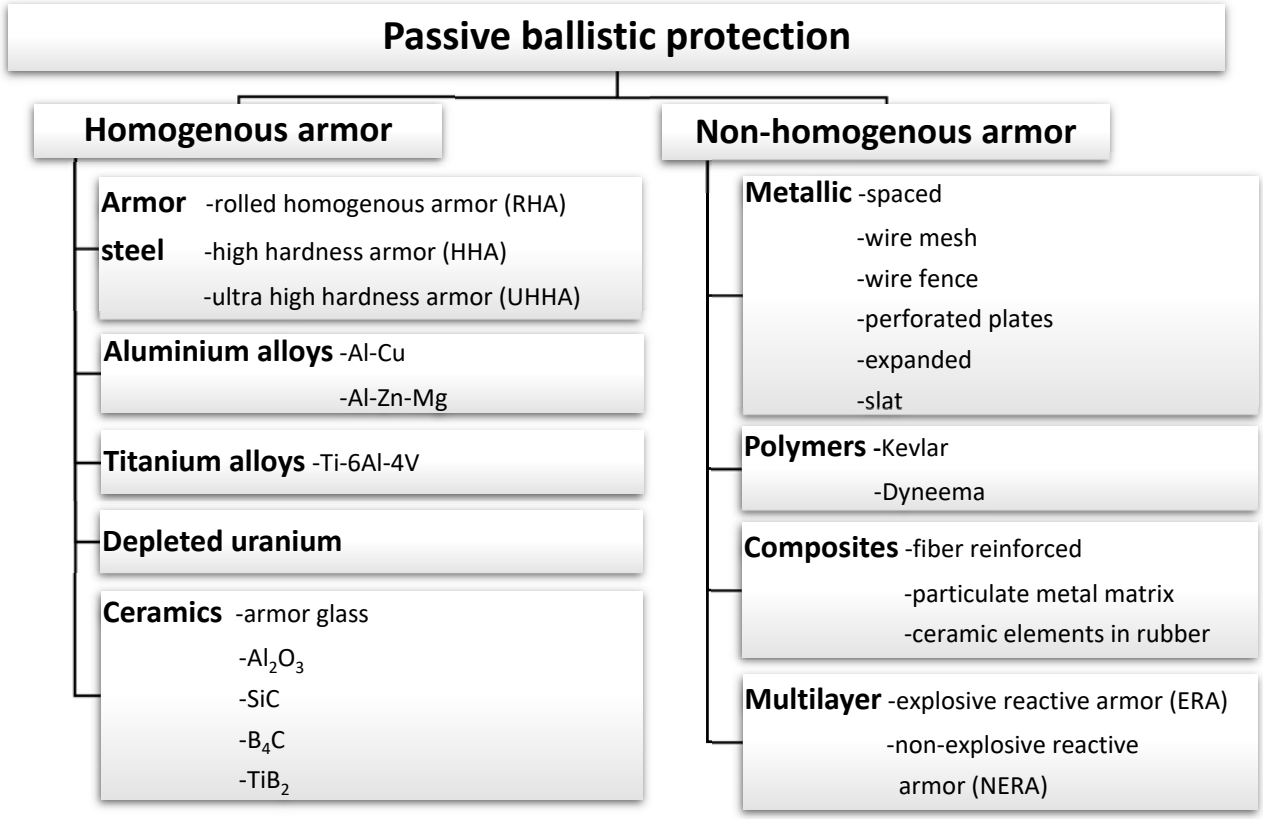

Figure 1. Passive armour materials and types.

Table 1. Typical thicknesses, areal densities and mass effectiveness of various types of armour [7].

	Thickness [mm]	Areal Density [kg/m^2]	Mass Effectiveness
380 BHN* rolled homogenous armour (RHA)	41	322	1.00
500 BHN* high hardness armour (HHA)	36	283	1.14
Aluminium alloy 5083	134	356	0.90
Aluminium alloy 7019	97	270	1.19
Aluminium alloy 7039	91	253	1.27
Titanium alloy Ti-6Al-4V	45	199	1.62
500 BHN* HHA and aluminium alloy 5083	-	192	1.68
500 BHN* HHA and titanium alloy Ti-6Al-4V		167	1.93
High hardness perforated plates and aluminium alloy 5083	-	168	1.92
Al_2O_3 ceramics and 500 BHN* HHA	-	152	2.12
Al_2O_3 ceramics and aluminium alloy5083		146	2.19
Al_2O_3 ceramic composite reinforced with glass fibers		141	2.28

* BHN—Brinell Hardness Number.

A similar type of non-homogenous armour appeared on Soviet T-34/85 tanks during the Battle of Berlin in 1945. It was in the form of bed frames with 1 mm diameter wire net to offer additional protection against shaped charges of German Panzerfaust recoilless

weapons [11]. Panzerfaust used an early generation shaped—charge warhead, just as was the M6 Bazooka and the German Panzerschreck, both very sensitive to increasing stand-off distance. At longer standoff distances, the jet defocuses and even fragments, degrading penetration effectiveness. After World War II, more advanced shaped—charges with higher penetration were developed, so spaced armour began to gain favor, along with different improvised add-on armours to protect from shaped—charges, such as logs, rubber sheets and wire mesh nets used in a number of local wars [3,5,12].

Recently, along with the tendency to use improvised add-on armours, there were attempts to develop wire meshes and fences from commercial off-the-shelf materials [13,14]. Balos et al. [13] have used the disrupting element of the fence made of Ø 5 mm patented wires containing 0.8% carbon ($Rp_{0.2\%}$ = 1410 MPa; Rm = 1630 MPa; A = 9.5%). The distance between the wires was 13–13.5 mm, placed in an L-profile frame in zig-zagged (Figure 2) and parallel configurations. Wire fences were mounted in stiff and free-hanging mounting. Base RHA, 460 BHN hard, 13 mm thick was mounted at 400 mm from the mesh. In this study, only the parallel wire arrangement proved ineffective, with the main defeating mechanism being the induction of yaw. Zig-zagged and angled configurations were fully effective, fulfilling the ballistic protection criterion set at stopping all five kinetic energy shots from a Browning M2HB 12.7 mm heavy machinegun. These configurations proved to be superior since the case where the projectile impacts two wires at the same time is completely excluded. A similar effect was observed by Balos et al. [14] where an even simpler and cheaper configuration was successfully applied: Ø 6 mm mild steels wire mesh ($Rp_{0.2\%}$ = 260 MPa; Rm = 380 MPa; A = 19%) with 50 mm distance between the wires was used to create a four-layer stepped-up multilayer mesh, with the distance between centers of wires of 16.75 mm. Having essentially a 3D configuration owing to the depth of the setup, a vertical mesh proved to be more effective than if inclined, which is quite opposite to results presented in the previous study [13]. The main reason for such behavior is the inclination itself. In such a setup, some inter-wire distances decrease, while others increase, representing a less effective yaw-inducer. To provide protection in such a configuration, an additional wire mesh layer might have been added, however, this could have only been done at the expense of an increase in weight.

Figure 2. Patented wires in a zig-zagged configuration useful in causing projectile yaw. Zig-zag configuration of patented wires is indicated by a broken black line [15].

2. Perforated Plates in Armoured Vehicles

One of the most effective light applique armour of the Cold War was the Israeli Toga, used on local modification of the American M113 armour personnel carriers (APC) Zelda-1 in 1972, one of the most widely used vehicles of this class. It consisted of perforated steel plates (~10 mm thick, with ~10 mm perforations with ~15 mm distance between their axes) all around the vehicle. When placed at some distance from the base armour, together with the base aluminium alloy (AA 5083) armour, it provided a significant increase in protection from 7.62 mm × 51 mm to 14.5 mm × 114 mm AP (Armor Piercing) ammunition [1,16]. This type of add-on armour was subsequently deployed for increasing the armour protection of other vehicles as well. Perhaps the most interesting being a range of Israeli heavy armoured personnel carriers (HAPCs) and even main battle tanks (MBTs) Merkava, the heaviest vehicle that uses this type of armour. In addition to this, perforated plates attracted considerable attention in other armed forces as well.

The American P900 type armour, consisted of two 500 BHN perforated plates 6.35 mm thick and appeared in two basic configurations. The first has the distance between perforated plates of 25 mm, with the inner perforated plate mounted at 182 mm distance from the base plate of the Dutch YPR-765 infantry fighting vehicle (IFV), itself a version of M113 APC. Again, in this vehicle, the base plate was AA 5083 aluminium alloy. The second configuration also consisted of two perforated plates placed at 22 mm distance between them, while the inner was mounted at 82 mm from the base aluminium alloy plate (M2/M3 Bradley), of AA 5083 aluminium alloy [17]. Howell et al. [18] successfully applied high manganese and aluminium austenitic steels as a basis for P900 perforated plate armour, effective against 7.62 mm AP ammunition.

United Kingdom has fielded an up-armoured light armoured fighting vehicle (AFV) Scimitar with perforated plates more similar in appearance to Toga [10]. Finally, there are indications that perforated plates were used in the Canadian version of the Leopard C2 main battle tanks (MBT). These perforated plates were coated in rubber and placed at turret sides. They were probably aimed at protecting the vehicle against 30 mm autocannon, due to a thicker base armour [10]. Although single or double perforated plates are the best known, an alternative approach was proposed in the patent by Auyer et al. [19]. In accordance with this patent, perforated plates with triangular holes were presented. Two such perforated plates were proposed to be mounted within the armour protection package in such a way, that hole patterns are offset in respect to each other. This was done so as to prevent straight-line penetration and facilitate the induction of asymmetric loading of the penetrating core of the projectile.

More specific data on perforated plate material was shared in [7,20]. It was claimed that M113 was being fitted with perforated plates made of MARS 300 ultra-high hardness steel, having the hardness of 578–655 BHN and relatively low Charpy impact strength at −40 °C of over 8 J. Although highly effective against 14.5 mm × 114 mm AP ammunition, the chemical composition with ≤0.55%C, ≤0.002%S, ≤0.01%P, ≤0.7%Mn, ≤1%Si, 2.4%Ni, ≤0.0.4%Cr and ≤0.5%Mo, provide carbon equivalent of CE ≤ 0.83 [21]. That means the welds are susceptible to cold cracking, rendering the overall weldability relatively low, suggesting bolting is the most convenient joining method. When combined with an aluminium alloy hull, inherent difficulties of joining steel and aluminium alloy due to the formation of intermetallic compounds (FeAl, Fe_3Al, Fe_2Al_3, $FeAl_2$, Fe_2Al_5, $FeAl_3$, $FeAl_6$) make the welding difficult in any case [22–25]. However, as ultra-high-strength steels prevail over aluminium alloys in today's armoured vehicles, perforated plates are made of weldable high-hardness steels (500–550 BHN) but with a lower carbon content, also used for base armour, might be a more effective option.

3. Basic Principle

The study by Chocron et al. [26] proved the basic principles of perforated plates, by applying the three-dimensional numerical simulations with the AUTODYN-3D code (Ansys, Canonsburg, PA, USA). It was determined that 7.62 mm × 51 mm M2 armour-piercing

(AP) round, when impacting the edge of the plate undergoes bending, Figure 3. It was found that 2% tensile strain is needed, representing a threshold over which the penetrating core of the projectile fractures. The penetrating core fracture is essential for a considerable reduction in penetration since the base plate can stop these fragments without significant damage. It must be noted that the penetrating core used in this test possessed a very high hardness of 62 HRC, which was necessary to provide sufficient penetration, however, that also means its ductility is relatively low, so even 2% strain is sufficient to fracture it. This relatively high hardness is characteristic of all AP, armour-piercing incendiary (API), armour-piercing tracer (APT) and armour-piercing incendiary tracer (APIT) penetrating cores of different ammunitions of different calibers. It was determined that the overlap threshold h/R is 0.34. Overlap threshold is important for correct geometry determination of the perforated plate: h—overlap between the penetrating core and the plate; R—radius of the penetrating core. In higher h/R values, no core fracture occurred, which means the induction of bend stress was not sufficient, since the projectile impacted the edge of the plate further away from the projectile point, that is, closer to the projectile cylindrical section. Numerical simulations done by Mubashar et al. [27] proved that the perforated plate causes the shattering of the projectile penetrating core into multiple fragments which were unable to penetrate the base armour plate. Furthermore, simulations done by Chocron et al. [26] proved that the induced strain increases with plate thickness. Computational data suggest that a strain of at least 2% is needed to cause the penetrating core fracture. In the case of 7.62 mm × 51 mm M2 AP ammunition used in the experimental part of this work, 3.175 mm perforated plate (Rp = 1400 MPa) is sufficient to effectively fracture penetrating core, which induces 2.5% strain, Figure 4. Aluminium alloy perforated plates were also tested (Rp = 380 MPa, 6.35 mm thick), which were not able to fracture the penetrating core, since the strain imparted to the penetrating core is slightly less than 2%. That means, either a stronger aluminium alloy is recommended, or a thicker perforated plate. The application of aluminium alloy perforated plate has merits, since its density is almost three times lower than that of steel [28], which, together with approximately twice the thickness theoretically needed to fracture the penetrating core, could result in significant savings in weight. Nevertheless, this remains to be addressed and ultimately experimentally proved. Furthermore, the joining of aluminium alloy to the steel vehicle hull would arise by bolting anyway, as is done traditionally with steel perforated plates. The main reason for this is the difficulties of aluminium alloy to ferrous alloys dissimilar welding, due to inherent difficulties of welding of high strength aluminium alloys themselves and the formation of Fe-Al intermetallics that severely degrade mechanical properties of welds, especially ductility [29–31].

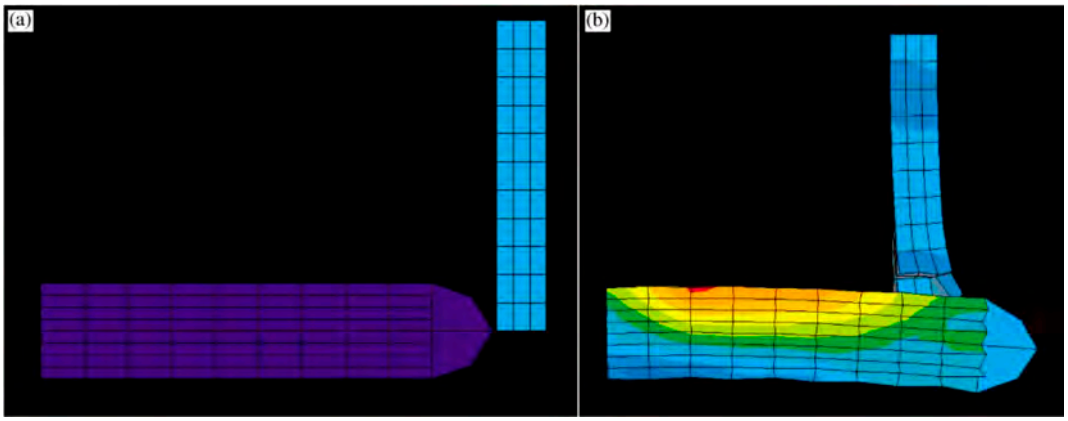

Figure 3. A simulation conducted by Chocron et al. [26]: (**a**) initial configuration; (**b**) 12 μs after impact showing bending and stress contours. Reprinted with permission from Elsevier: *Int. J. Impact Eng.*, Copyright 2021, License: 5017580939892.

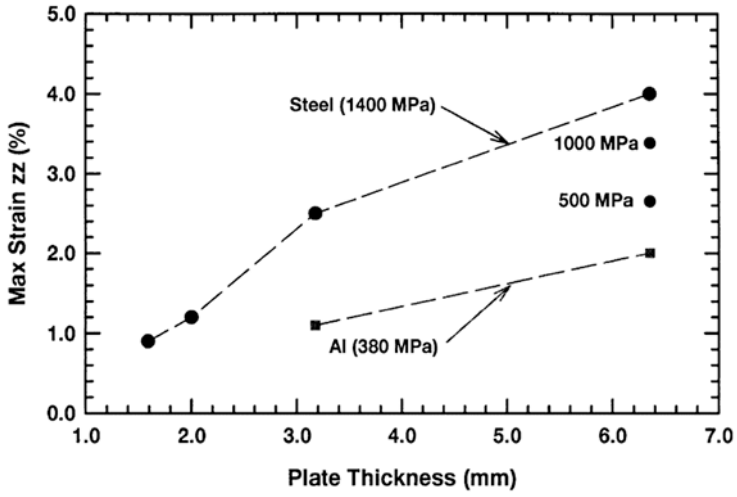

Figure 4. Maximum strain in the projectile core versus target thickness [26]. Reprinted with permission from Elsevier: *Int. J. Impact Eng.*, Copyright 2021, License: 5032390676694.

4. Perforated Plate Geometry and Materials

The works of Balos et al. [32] and Radisavljevic et al. [33] represented continuous development efforts to optimize the material, geometry and mounting of perforated plates, in order to increase mass efficiency and multi-hit resistance of the perforated plate and armour system as well. Along with the performance of a particular perforated plate in terms of ballistic resistance, a number of interconnected holes and damaged areas were reported. The number of perforated plates and damaged areas was used to describe the multi-hit resistance, a significant advantage over less effective armour types in this respect, such as various types of RHA, and conventional ceramic tiles in particular [34–36] The base plate was 13 mm RHA, having a hardness of 460 BHN, while test ammunition was 12.7 mm × 99 mm M8 API. It was found that a perforation diameter lower than Ø 9 mm and thicknesses under 6 mm, proved ineffective in both inducing sufficient bed stresses to cause penetrating core fracture and preventing the API ammunition to penetrate base armour. On the other hand, these studies [33,37] have shown that larger perforations are more effective, due to a more potent bend stress induction potential.

The depiction of various successful geometries is shown in Table 2. The main criterion for full ballistic protection was that no projectile penetrated the basic RHA plate (zero penetration criteria). Larger perforations (Ø 11 mm) resulted in a more effective fragmentation of the penetrating core: Ø 9 and 10 mm perforations resulted in fragmentation of the penetrating core into maximal five fragments, while perforations of Ø 11 mm caused the fracture of into maximal six parts, with a less severe base armour plate damage. That means, to achieve protection from a larger number of smaller fragments, a thinner and lighter base plate could be used, lowering the weight, and therefore, the areal density of the armour system. In addition to perforated plates made of different types of steels, the results depicting the geometry and effectiveness of heat-treated austempered ductile iron (ADI) and austempered compacted graphite iron (ACGI) perforated plates are also shown in Table 2, extracted from studies by Balos et al. [37,38]. Typical perforated plate and base plate damage (core fracture in two pieces) are given in Figure 5.

Table 2. Geometry, the average number of interconnected perforations, damaged area, areal density and mass effectiveness of various successful perforated plates [10,35,37,38].

Performances	**Perforated Plate Material**					
	50CrV4	H9-6-0	H10-6-0	H11-6-0	ADI-275	ACGI-275
Thickness [mm]	6	6	6	6	7	7
Perforation diameter [mm]	9	9	10	11	11	11
Ligament length [mm]	4.5	4.5	3.5	3.5	3.5	3.5
Inclination [°]	20	0	0	0	0	0
Maximal number of fractured parts	2	5	3	6	3	3
Average no. of interconnected perforations	6	6.4	6.2	5.8	7.2	7.8
Damaged area [mm^2]	448	483	487	551	2076	2214
Perforated plate areal density [kg/m^2]	30	28	24	23	24	24
Armour system areal density (perforated + base plate) [kg/m^2]	132	130	126	125	126	126
Mass effectiveness of the perforated plate vs. 380 BHN RHA	3.93	4.21	4.92	5.13	4.92	4.92
Mass effectiveness of armour system vs. 380 BHN RHA	1.67	1.69	1.75	1.76	1.75	1.75

Mechanical properties of perforated plate materials are: 50CrV4: $Rp_{0.2\%}$ = 1410 MPa; Rm = 1470 MPa; A = 6%. H: $Rp_{0.2\%}$ = 1255 MPa; Rm = 1140 MPa; A = 11%. ADI-275: Rm = 1472 MPa; A = 1%. ACGI-275: $Rp_{0.2\%}$ = 1310 MPa; Rm = 1364 MPa; A = 1%.

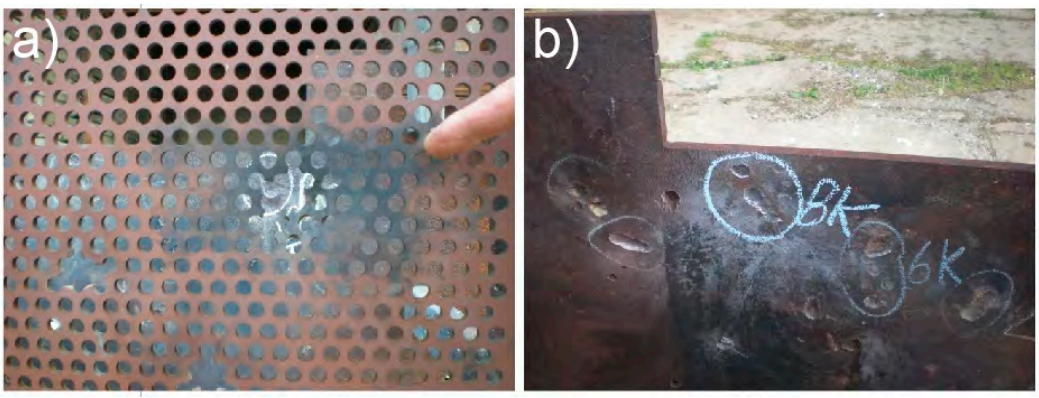

Figure 5. Perforated plate damage (**a**); base plate with two dents on the base plate (**b**) [15].

The average number of interconnected perforations in steel specimens drops as the perforations become larger for the same material (H9-6-0, H10-6-0, H11-6-0). However, a quite opposite trend can be observed in terms of the damaged areas. The main reason is the fact that perforations are larger, so that the damaged area increases. The average number of interconnected perforations is higher in cast irons (ADI-275, ACGI-275), but the main drawback is the damaged area which is significantly larger, potentially leaving larger unprotected areas that may not cause any interaction with the subsequently fired incoming projectile, which would most likely penetrate the base armour.

Higher mass effectiveness in perforated plates with larger perforations results in a smaller number of interconnected perforations, but on the other hand, the damaged area is larger, Table 2. It can be seen that cast irons (ADI and ACGI) represent an interesting alternative to steels, due to their relatively high tensile strength and a lower density. Considerably lower elongation, which represents the measure of the material's ductility, does not affect these perforated plates' mass effectiveness but lowers the perforated plate multi-impact properties. It must be noted that ADI-275 and ACGI-275 targets were not made of a single plate, but rather of several smaller (210 mm × 130 mm) plates bolted together, Figure 6. This was done due to the salt bath size available for specimen heat treatment. Areal density and mass effectiveness data for ADI-275 and ACGI-275 given in Table 2 do not take into account joining bolts and plates.

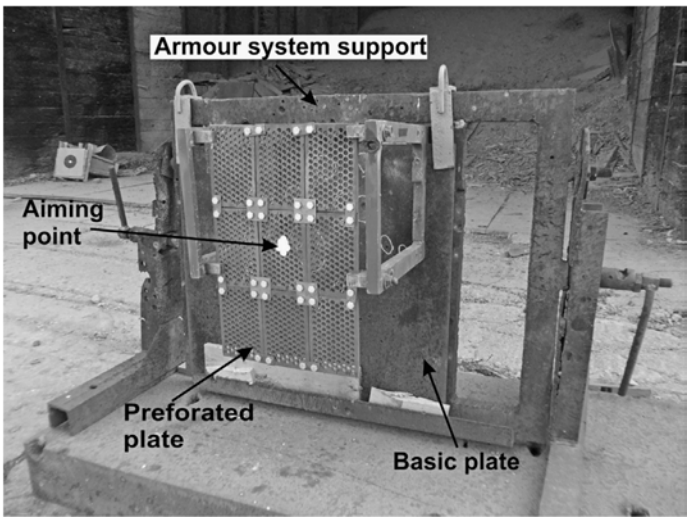

Figure 6. Test setup with the austempered ductile iron (ADI) material perforated plate made of nine smaller perforated plates joined by bolts [37]. Reprinted with permission from Elsevier: *Mater. Des.*, Copyright 2021, License: 5027070247748.

The particular design of perforated plates overcomes the problem in ductility, providing significant mass effectiveness, since the crack propagates to the nearest perforation, where it is stopped from further propagation. Typical damage in differently heat-treated ADI materials is shown in Figure 7. It can be seen that intensive cracking and no plastic deformation occur in ADI-275 material, which is in contrast to the softer and more ductile ADI-400 material. In spite of that, the results suggest that a softer and more ductile ADI-400 does not offer sufficient induction of bend stresses in the projectile penetrating core to cause its fracture or sufficient yaw to prevent it from penetrating the base armour. A lower density of ADI and ACGI materials was certainly beneficial since it enabled the increase in the thickness of cast iron perforated plates further adding to their bend stress induction potential and effectiveness. Probably the most significant advantage of cast materials such as ADI and ACGI is a relatively low cost compared to steel perforated plates, both in the simplicity of manufacture of the material itself and perforation fabrication. Namely, the fabrication by drilling of already heat-treated steels, particularly armour steels is very difficult, so a more expensive waterjet is usually applied. The logistics required for the manufacture of rolled steels is more significant than casting iron and steel [38,39].

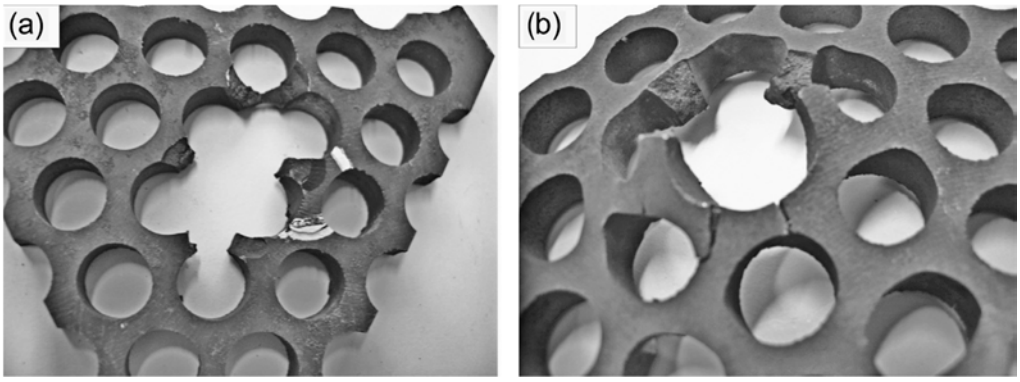

Figure 7. Damage on the back of the perforated plate: (**a**) ADI-275; (**b**) ADI-400 [37]. Reprinted with permission from Elsevier: *Mater. Des.*, Copyright 2021, License: 5027070247748.

Another approach is to apply a cheaper and quicker alternative to the waterjet process of perforated plate fabrication [40]. In this work, armour steel was subjected to a laser

cutting process with three cutting speeds, 1000, 1200 and 1400 mm/min, with a respective number of perforations drilled: 80, 100 and 120 min^{-1}. In this study, 4.2 kW laser was used, with 40% oxygen 60% nitrogen cutting gas and 2 mm beam diameter. As the cutting speed was higher, the heat-affected zone was narrower, perforation surface roughness was lower and the perforation edge was less perpendicular to the plate surface. The optimal laser cutting speed was 1200 mm/min, providing intermediate properties.

All previous studies used API ammunition, which possesses the incendiary mixture between the jacket and penetrating core. This effectively ignites the fuel inside of an aircraft or a vehicle. However, although these temperatures are well within the transformation range for materials used (tempering 200–450 °C), no phase transformations were detected in the perforated plate due to a very short time of perforated plate exposure [41].

5. Finite Modelling and Ballistic Testing

The majority of studies tested circular perforations, which are the most convenient for machining—drilling. However, in the case of an alternative fabrication method, such as waterjet, the perforation shape can easily be altered. In studies by Fras et al. [42,43], slotted-type perforations of 4 mm × 12 mm size were used, Figures 4 and 5. Perforated plates were made of super-bainitic Ultra-High Hardness Perforated Armour Steel Pavise™ (Tata Steel, Mumbai, Maharashtra, India) SBS600P steel, 600–670 BHN, 4 mm thick, while the basic plate was 8 mm MARS 190 400 BHN plate. The projectile was 7.62 mm × 51 mm with a hardened steel core and impact velocity of around 820 m/s. Various impact points were tested and numerically simulated by means of LS-DYNA Johnson–Cook flow and fracture models. The two least convenient impacts were in an area between perforations (Figure 8) and in the center of the perforation (Figure 9). Although less effective compared to edge impact, where intensive core fracture was observed, in these cases, projectile deviation from its initial trajectory is the main defeat mechanism. Even if the tip was not damaged, the side impact did not penetrate the base armour, which is similar to the results obtained with wire meshes, as published in [15].

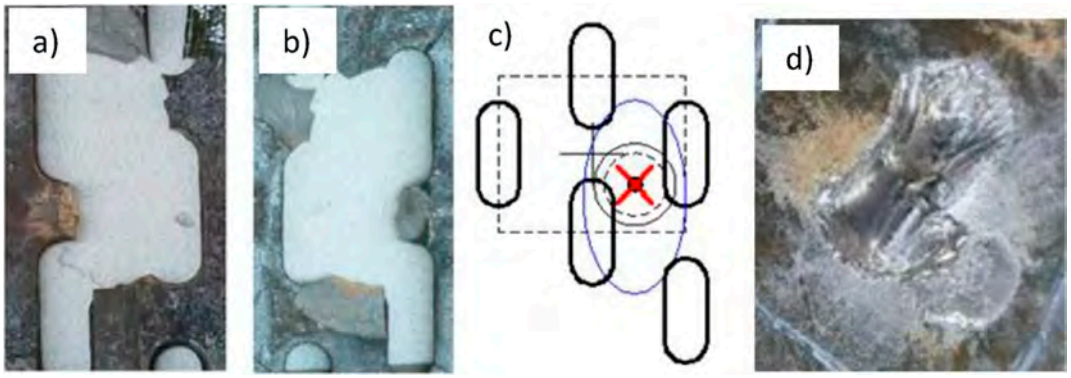

Figure 8. Damage of the perforated plate after the impact in an area between perforations: (**a**) front side; (**b**) rear side; (**c**) schematic view of the damaged area; (**d**) deformation of the base armour [43]. Reprinted with permission from Elsevier: *Int. J. Impact Eng.*, Copyright 2021, License: 5017590451474.

Kilic et al. [44,45] correlated the finite-element method using LS-Dyna with Lagrange discretization for experimental evaluation of perforated plates. Several penetrating core-defeating mechanisms were identified: asymmetric forces causing the projectile to deviate from incident trajectory (yaw), penetrating core fracture and penetrating core nose erosion. Various cases where the projectile impacts different places of the perforated plates are shown in Figure 10. It can be noted that the most likely impact is shown in Figure 10b. Cases in which the projectile impacts the perforation center and the geometrical center between three perforations result in penetration of the base plate since no lateral forces and stress induction occurs. However, these cases are extremely rare due to a low probability of such impact at this spot and because shooting at exactly 90° to the hull—a

perfect defilade shot. These results are confirmed with experimental research, by applying 7.62 mm × 54R mm ammunition, 6 mm perforated plate and 9 mm base plate, 500 BHN hard. It was found that after passing through the perforated plate, the impact into the base plate resulted in an indentation depth of only 1.8 mm, confirming that the base plate thickness could have been considerably lower than the one used. Furthermore, such damage is considerably lower compared to the damage of a single 15 mm 500 BHN armour plate that was used as a reference. There were no traces of sharp intrusion into the base plate, meaning that a yawed impact was present, or the nose of the projectile was eroded or fractured. It can be deduced, that for mass effectiveness reduction, a thinner perforated plate than 6 mm could have been applied, since, in previously presented studies, the 6 mm perforated plate was found to be effective against a much more potent 12.7 mm × 99 mm or 12.7 mm × 108 mm ammunition types, with roughly four times higher kinetic energy. If correlated to the work by Chocron et al. [26], who used 7.62 mm × 51 mm, similar in kinetic energy to 7.62 mm × 54R mm used by Kilic et al. [44,45], it can be deduced that 3–4 mm perforated plate might be sufficient for penetrating core fracture.

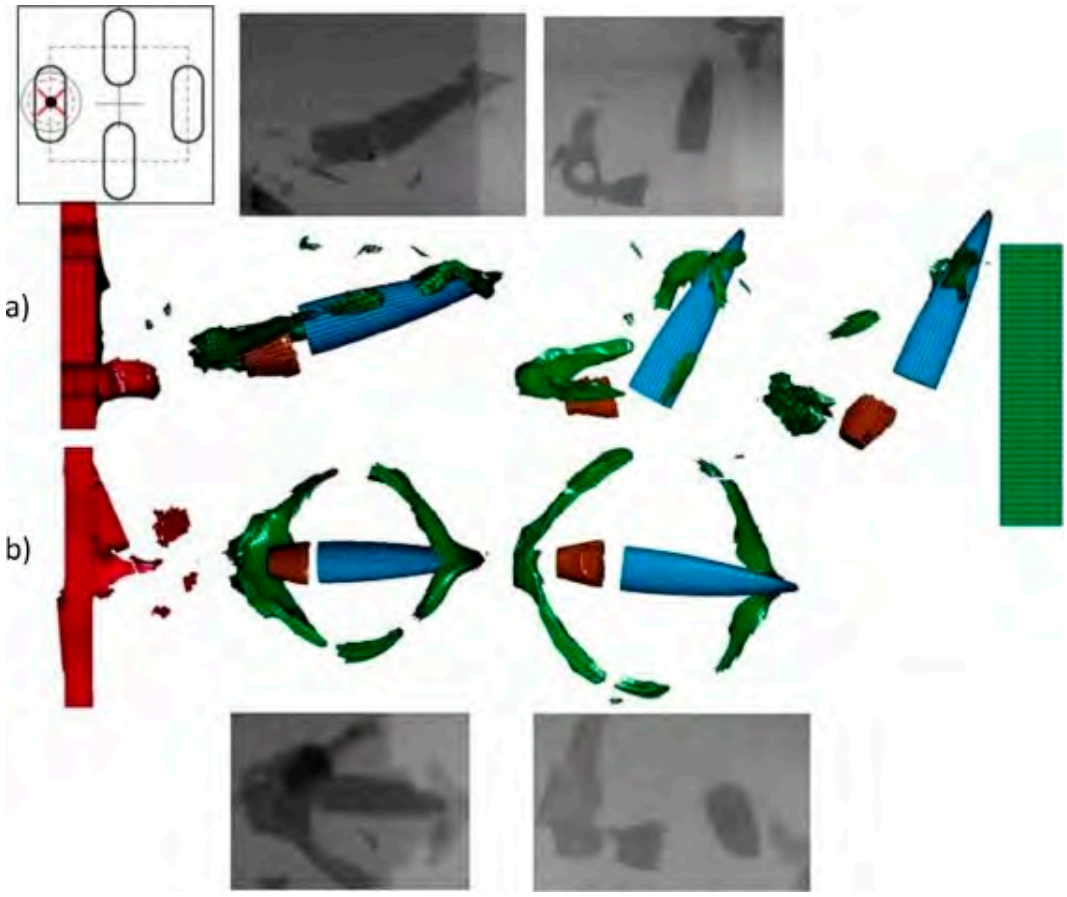

Figure 9. Numerical results of the AP impact in the center of the perforation compared with the flash X-ray images: (**a**) bottom view; (**b**) side view [43]. Reprinted with permission from Elsevier: *Int. J. Impact Eng.*, Copyright 2021, License: 5017590451474.

Mishra et al. [46,47] ballistically tested quenched and tempered steels (200–600 °C), along with the perforated plate placed on top of the 7017 aluminium alloy, Figure 11. It was found that the adiabatic shear band (ASB) induced cracking occurs in tested steels tempered at 400 °C or below. In perforated plate steel, however, ASB-induced crack formation can be partially inhibited due to the presence of perforations, (Figures 12 and 13). This makes the perforated plate material more resistant to multiple impacts compared to homogenous steel. Placing the perforated plate on top of the base aluminium alloy (without spacing) has

considerable merit since the distance between the base plate and perforated plate inevitably increases the vehicle footprint, which might limit the number of vehicles transported by ships or even limit and prevent the vehicle transportability by certain types of transport aircraft or limit the vehicle to wider streets.

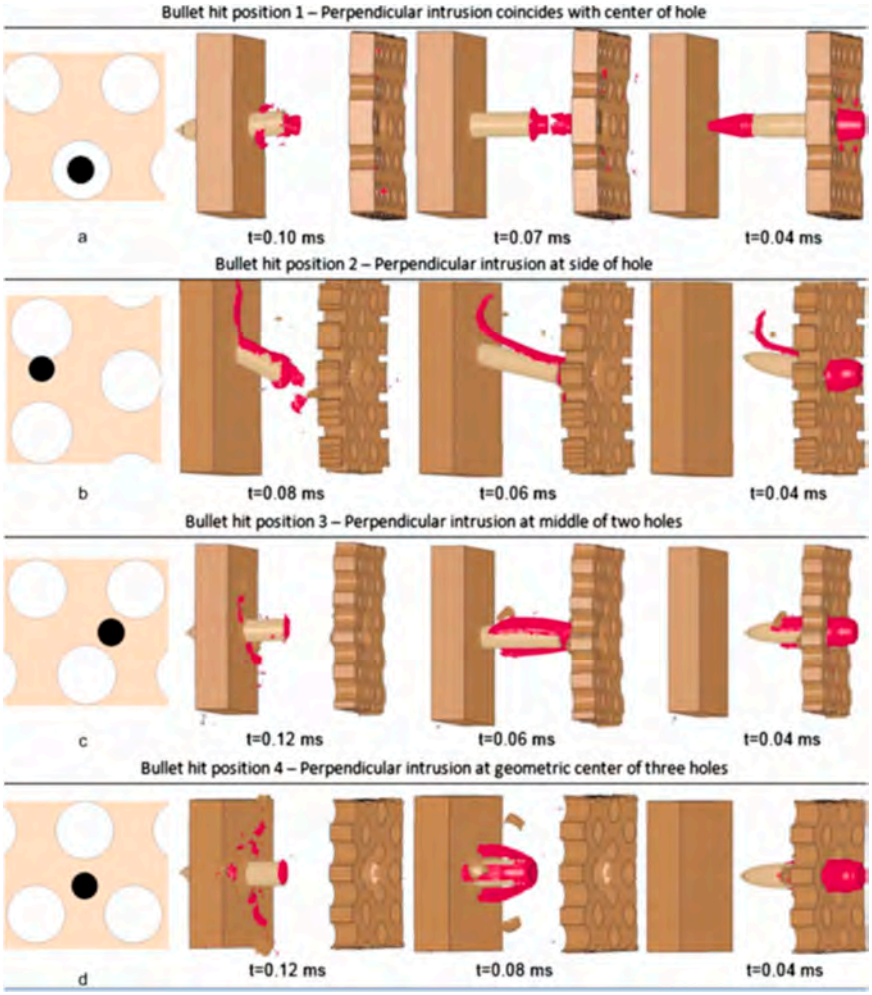

Figure 10. Projectile impacts in the perforated plate: (**a**) center of the hole; (**b**) hole side; (**c**) between two holes; (**d**) geometric center between three holes [44]. Reprinted with permission from Elsevier: *Mater. Des.*, Copyright 2021, License: 5017590846392.

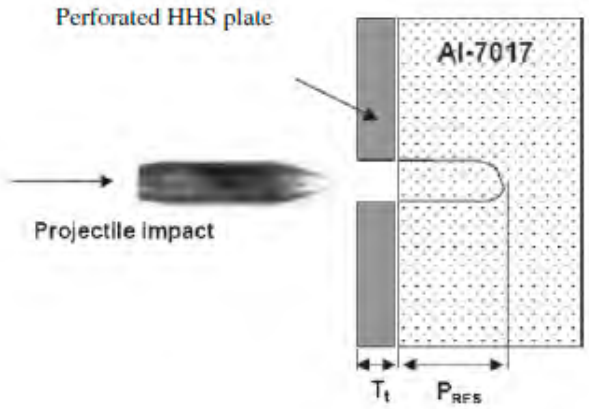

Figure 11. Target configuration studied in [47]. Reprinted with permission from Elsevier: *Mater. Des.*, Copyright 2021, License: 5027070526474.

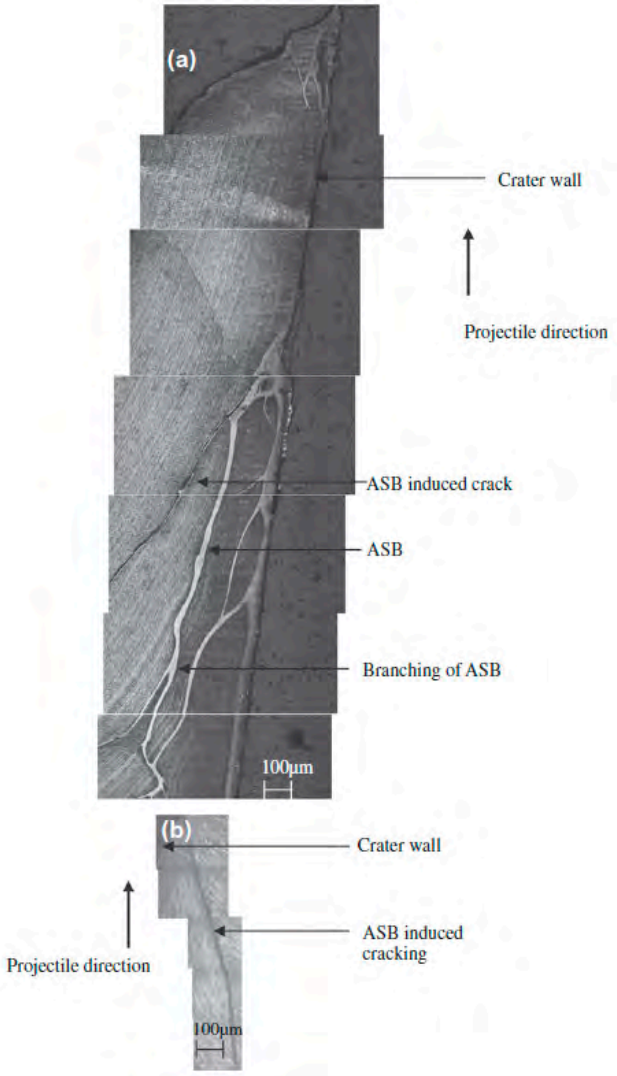

Figure 12. Micrograph of the through thickness of (HHS + Al-alloy; HHS-High Hardness Steel configuration (**a**) front HHS steel plate (**b**) backing Al-alloy plate. The arrow shows the direction of the projectile [47]. Reprinted with permission from Elsevier: *Mater. Des.*, Copyright 2021, License: 5017591074019.

Square and circular perforations were made (2, 4 and 6 mm) into 5 mm heat-treated chromium-nickel steel. The base plate was 60 mm thick and also acted as a witness plate to measure residual penetration, which was used as a measure of mass effectiveness of the perforated plate. It was shown that the highest mass efficiency was achieved by the largest perforations, which were the closest in size to the diameter of 7.62 mm × 51 mm penetrating core used in the test, confirming the results from Radisavljevic et al. [33]. A very important result was that 2 mm perforations did not result in any penetrating core fractures. Very slight differences between perforation sizes existed: 6 mm square shape proved superior compared to 4 mm size, suggesting that the perforation shape should be selected based on the manufacturing method. Interestingly, the damage of perforated plate with square and circular perforations is similar, note white squares in Figure 14. This indicates that stress concentration in the edges of the square perforations does not have a crucial influence on perforated plate damage. Admittedly, in this work, an unusual perforation fabrication method was used, electric discharge machining (EDM) which is both slow and expensive, and therefore, difficult to apply to large-scale industrial manufacturing conditions. It is difficult to compare these results to the results of Balos et al. [37], Radisavljevic et al. [33] and Kilic et al. [44] since the lack of spacing between perforated plates and basic plates

might reduce the effectiveness of the armour system. Therefore, it is possible that a 5-mm perforated plate can be essential for achieving a sufficient protection level since the lack of spacing might stabilize the tip of the projectile, prevent its lateral movement and make the fracture of the penetrating core more difficult. This certainly is an attractive field where further work is needed to be done.

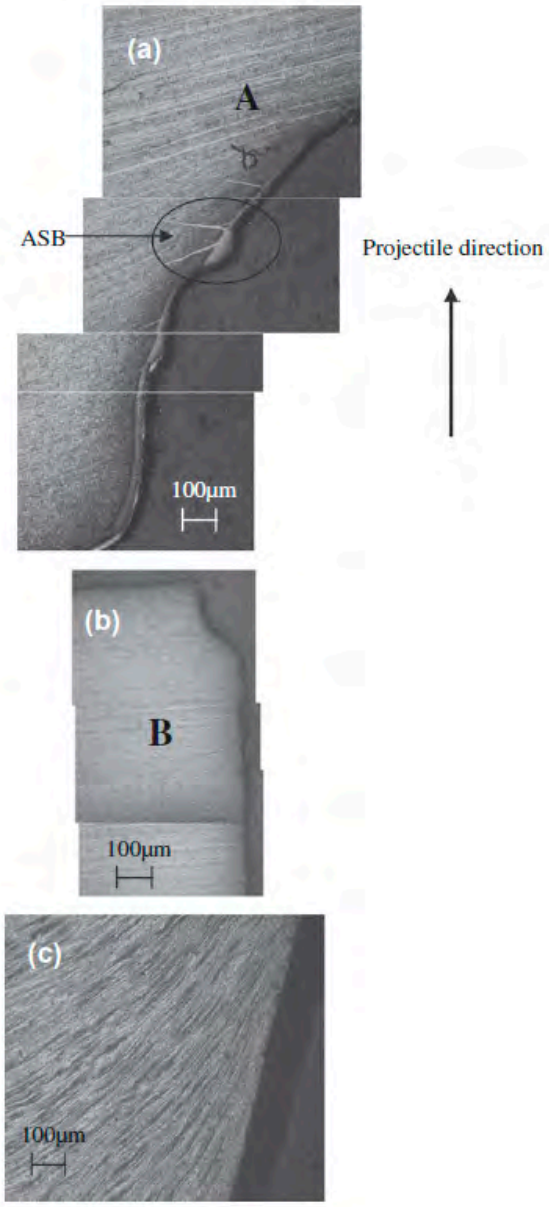

Figure 13. Micrograph of through thickness region of (PHHS + Al-alloy; PHHS-Perforated High Hardness Steel) configuration having 6 mm square holes (**a**) side A of front PHHS plate, (**b**) side B of front PHHS plate and (**c**) backing Al-alloy plate. The arrow shows the direction of the projectile. [47]. Reprinted with permission from Elsevier: *Mater. Des.*, Copyright 2021, License: 5017591074019.

Another interesting material that can be applied for perforated plates is the nanostructured bainitic steel published in the work by Burian et al. [48]. This material, having the chemical composition of 0.55C–2.0Mn–1.8Si–1.37Cr–0.7Mo–0.11 V (wt.%); was hot forged and rolled into plates. Subsequently, austenitization was performed, followed by controlled cooling to isothermal transformation at 210 °C for 2 h. This resulted in obtaining the following mechanical properties: Re = 1300 MPa; Rm = 2050 MPa; A = 12%, while the hardness was 640 VHN. The perforated plate 6 mm thick was effective against 7.62 mm

× 54R mm B-32 API ammunition with steel core so that a very intensive fragmentation occurred. It was shown that the penetrating core fractured into up to eight fragments, demanding a relatively thin basic plate to completely prevent penetration. At the same time, an excellent correlation between finite element modeling and ballistic testing results was obtained, Figure 15.

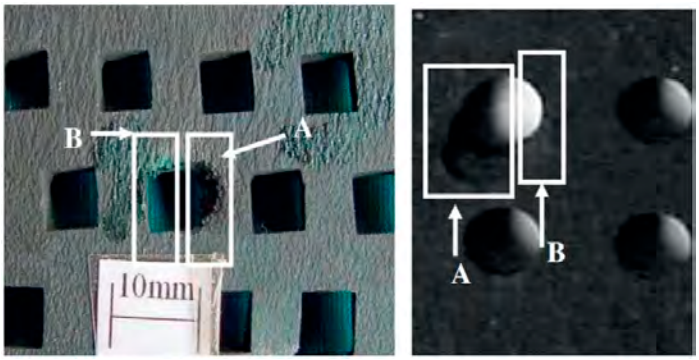

Figure 14. 6 mm square and circular perforation damage: area A is the deformed and area B is the non-deformed region of a similar morphology [47]. Reprinted with permission from Elsevier: *Mater. Des.*, Copyright 2021, License: 5027070526474.

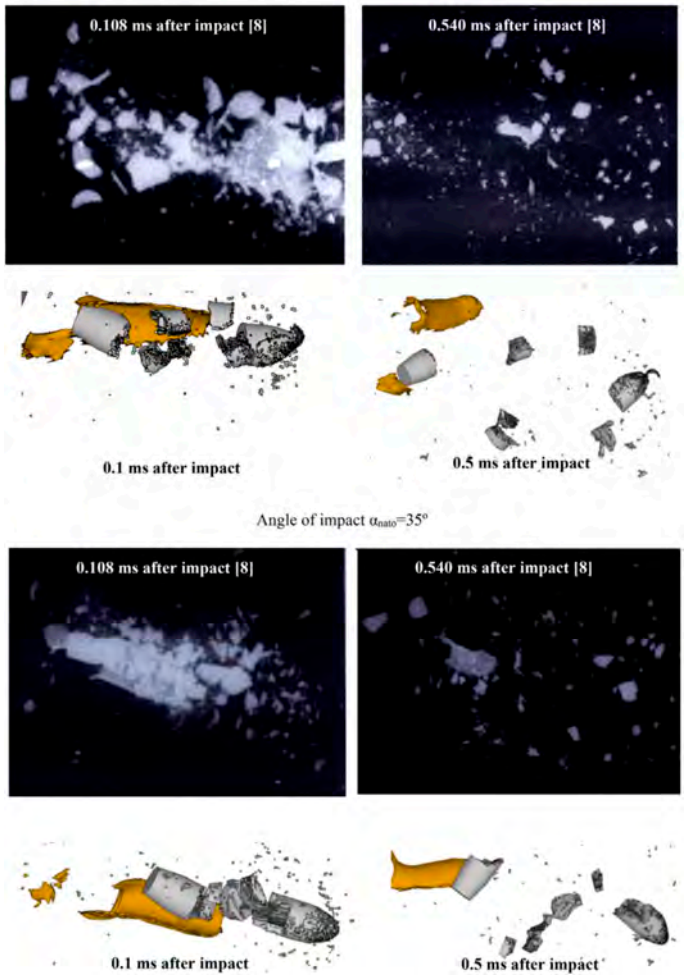

Figure 15. Comparison of the projectile fragmentation obtained experimentally and in the simulations with the use of principal stress/strain failure criterion applied for the hardened steel cores [48]. Reprinted with permission from Elsevier: *Int. J. Impact Eng.*, Copyright 2021, License: 5017591423106.

The application of amorphous alloy reinforced perforated armor (ARPA) was suggested by Cui et al. [49]. The main advantage of the amorphous component with random atomic arrangement compared to the common crystalline atomic arrangement is a unique combination of mechanical properties. Typically, amorphous metals possess higher specific strength and hardness, that are essential in providing a relatively high resistance of armor materials [50–53]. However, a lower impact strength is offset by the inherent crack arresting properties of perforated plates. In [49], the effect of various ARPA thicknesses, from 0 to 1.5 mm over the RHA base perforated plate (overall thickness 6 mm) were analyzed. It was found that the increase in ARPA thickness enhances the effectiveness of the perforated plate by increasing the projectile erosion.

An attractive, yet relatively simple use of perforated plates is demonstrated in the work by Chao et al. [54]. Perforated plates with the hardness of 500 BHN, with 4, 5 and 6 mm thicknesses, Ø5 and 6 mm perforations and 10 and 12 mm distance between perforation centers, were tested against 7.62 mm × 54R mm B32 API ammunition. It was shown that when mounted at extreme obliquity of 76°, both perforated plate and homogenous plate can provide projectile ricochet. However, being perforated, the weight of these plates can be significantly reduced. In this study, 26.24% weight reduction was achieved by the application of perforated versus the homogenous plate.

6. Blast Passive Mitigation

Besides kinetic energy ammunition, the highest threat to military vehicles in the last 20 years were shaped charges and IEDs (Improvised Explosive Devices) [10]. The effect of perforated plates versus shaped charges refers to increasing the stand-off distance, as in any other spaced armor, albeit at lower weight since perforations reduce the weight of the armor system. Older-shaped charges were more sensitive to this effect; however, more modern ones cannot be defeated completely. The effect of increasing the stand-off distance is more related to mitigating their effect, that is, the decreasing of the so-called lethal cone. On the other hand, several references explain the mechanisms and the potential of perforated plates in the respect of IED blast mitigation. So far, there were three main aspects of blast mitigation: energy absorption, blast deflection and keeping an adequate distance from detonation point [55]. Langdon et al. [56,57] and Ciortan et al. [58] proposed the application of perforated plates and perforated multilayer structures, respectively. Langdon et al. [56] reported that one deformable mild steel perforated plate, 2 mm thick can reduce deflection of the 1.6 mm reference target plate by 65–75%, while two 2 mm perforated plates of the same type, by 90–95%. Thus, perforated plates proved very effective in mitigating blasts, although large plastic displacement of the perforated plates was observed. On the other hand, in the work done by Ciortan et al. [58], who simulated the effect of 6.5 mm perforated plate, placed at 200 mm distance from the multilayer composite base plate (Kevlar, Aluminium, Armco iron, Aluminium, Kevlar), simulating the base vehicle armor. Interestingly, 6.5 mm thick perforated plates closely correspond to perforated plates effective against 12.7 mm M8 API ammunition, used in experiments by Balos et al. [13,14,19,32,35] and Radisavljevic et al. [33]. It was shown that a perforated plate effectively mitigates the effect of 5 kg TNT which is similar to a typical anti-tank mine.

7. Concluding Remarks

Based on the review presented, the following conclusions can be drawn:

- Perforated plates work mainly through stress induction in the projectile, causing fractures of the penetrating core of armor-piercing ammunition. Penetrating core fracture occurs as strains above 2%. Besides penetrating core fracture, which is the optimal case, perforated plates work through inducing yaw and penetrating core tip damage and erosion.
- The perforated plate-based armor system has an exceptional multi-hit resistance due to crack arrest by the nearest perforation. For further crack initiation and propagation, another impact is required in the damaged region. ASB-induced crack formation can

be partially inhibited due to the presence of perforations, making the perforated plate material more resistant to multiple impacts compared to homogenous steel.

- Perforated plates placed directly on the basic armor also induce bend stresses in the penetrating core, but as the projectile tip becomes embedded in the base plate, fracture potential might be reduced, rendering the need to increase the thickness of the perforated plate.
- Besides heat-treated steels, commercial and armor steels, nanostructured bainitic steels and austempered ductile and compacted graphite irons can be used, essentially enabling a wide variety of materials and fabrication processes to manufacture perforated plates.
- Considerable potential exists for applying amorphous metals to reinforce the crystalline base structure of the perforated plate, but this remains to be proved experimentally, as only simulations proved its merit. Simulations proved the potential of using high-strength aluminium alloys.
- If spaced, perforated plates inevitably increase the footprint and weight of the vehicle, which is a major deficiency. However, a perforated plate placed directly on the base plate deserves more attention from the point of view of defeating kinetic energy rounds, while optimizing parasitic weight and volume. A perforated plate placed directly at the base armor will have a negligible effect against shaped charges and IEDs.
- Even relatively thin perforated plates placed at some distance from the base plate significantly mitigate the effects of a blast from IEDs, providing higher survivability of the vehicle in the contemporary battlefield.

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References

1. Miller, D.; Foss, C. *Modern Land Combat*; Salamander: London, UK, 1987.
2. Hilmes, R. *Brassey's Multilingual Military Dictionary*; Brassey's Defence Publishers: London, UK, 1987; pp. 71–79.
3. Djordjevic, M. *Tenkovi 1945-2005*; NIU Vojska: Belgrade, Serbia, 1997.
4. Djordjevic, M. Future Armoured Troop Carrying Vehicles. *Odbrana, 76; Arsenal, 23* **2009**, 9–24.
5. Djordjevic, M.; Arsic, S. *Oklopni Transporteri 1945–2005*; NIU Vojska: Belgrade, Serbia, 2001.
6. Odanović, Z.; Bobić, B. Ballistic Protection Efficiency of Composite Ceramics/Metal Armours. *Sci. Rev.* **2003**, *53*, 30–37.
7. Ogorkiewitz, R. Armor for Light Combat Vehicles–Advances in Armour Materials. *Int. Def. Rev.* **2002**, *35*, 41–45.
8. Phelps, W.; Schoeters, R. *Panzer Survivors: Panzerkampfwagen IV Ausf. A-J*; Masalai Press: Oakland, CA, USA, 2005.
9. Jenz, T.; Doyle, D. Drachtgeflectschuerzen. *AFV News* **2002**, *37*, 6–8.
10. Balos, S. *Non-Homogenous Spaced Metallic Armour for Armoured Vehicles*; University of Novi Sad: Novi Sad, Serbia, 2010.
11. Grove, E. *World War II–Tanks*; Orbis Publishing: London, UK, 1976.
12. Ogorkiewitz, R. *Technology of Tanks*; Jane's Information Group: Coulsdon, Surrey, UK, 1991.
13. Balos, S.; Grabulov, V.; Sidjanin, L.; Pantic, M. Wire Fence as Applique Armour. *Mater. Des.* **2010**, *31*, 1293–1301. [CrossRef]

14. Balos, S.; Pecanac, M.; Trivkovic, M.; Sidjanin, L. Ballistic Behavior of Multilayer Wire Mesh Application Armor. *Adv. Technol. Mater.* **2019**, *44*, 7–11. [CrossRef]
15. Balos, S. Unpublished Material. Personal Collection. 2009.
16. Ogorkiewitz, R. Advances in Armour Materials. *Int. Def. Rev.* **1991**, *4*, 349–352.
17. Radetic, M. Pravci Daljeg Razvoja Borbenih Vozila Pesadije. *Vojn. Glas.* **2001**, *1*, 83–100. [CrossRef]
18. Howell, R.A.; Montgomery, J.S.; Van Aken, D.C. Advancements in Steel for Weight Reduction of P900 Armor Plate. *Iron Steel Technol.* **2009**, *6*, 168–176.
19. Auyer, R.; Buccellato, R.; Gidynski, A. Perforated Plate Armor. U.S. Patent No. 5,014,593, 14 April 1991.
20. Ogorkiewicz, R.M. Shifting Focus: Armored Vehicle Protection Adapts to New Threats. *Janes Int. Def. Rev.* **2007**, *40*, 35–43.
21. Arcelor Mittal MARS 300 brochure. Available online: https://industeel.arcelormittal.com/wp-content/uploads/2018/06/DS-PROTECTION-MARS300-GB.pdf (accessed on 22 February 2021).
22. Atabaki, M.M.; Nikodinovski, M.; Chenier, P.; Ma, J.; Harooni, M.; Kovacevic, R. Welding of Aluminum Alloys to Steels: An Overview. *J. Manuf. Sci. Prod.* **2014**, *14*, 59–78. [CrossRef]
23. Potesser, M.; Schoeberl, T.; Antrekowitsch, H.; Bruckner, J. The Characterization of the Intermetallic Fe-Al Layer of Steel-aluminum Weldings. In Proceedings of the EPD Congress, The Minerals, Metals & Materials Society, San Antonio, TX, USA, 12–16 March 2006; pp. 167–176.
24. Haidara, F.; Record, M.C.; Duployer, B.; Mangelinck, D. Phase Formation in Al-Fe Thin Film Systems. *Intermetallics* **2012**, *23*, 143–147. [CrossRef]
25. Bruckner, J. Considering Thermal Processes for Dissimilar Metals–Joining Steel to Aluminum in Heat-intensive Applications. *Fabricator* 28 August 2003.
26. Chocron, S.; Anderson, C.E.; Grosch, D.J.; Popelar, C.H. Impact of the 7.62-mm APM2 Projectile against the Edge of a Metallic Target. *Int. J. Impact Eng.* **2001**, *25*, 423–437. [CrossRef]
27. Mubashar, A.; Uddin, E.; Anwar, S.; Arif, N.; Waheed Ul Haq, S.; Chowdhury, M.A.K. Ballistic Response of 12.7 mm Armour Piercing Projectile against Perforated Armour Developed from Structural Steel. *Proc. Inst. Mech. Eng. Part L J. Mater. Des. Appl.* **2019**, *233*, 1993–2005. [CrossRef]
28. Smallman, R.E.; Bishop, R.J. *Modern Physical Metallurgy & Materials Engineering*, 6th ed.; Butterworth Heinemann: Woburn, MA, USA, 1999.
29. Agudo, L.; Eyidi, D.; Schmaranzer, C.H.; Arenholz, E.; Jank, N.; Bruckner, J.; Pyzalla, A.R. Intermetallic Fe x Al y-phases in a Steel/Al-alloy Fusion Weld. *J. Mater. Sci.* **2007**, *42*, 4205–4214. [CrossRef]
30. Mendez, P.; Eagar, T. New Trends in Welding in the Aeronautic Industry Bilboa, Spain. In Proceedings of the 2nd Conference of New Manufacturing Trends, San Sebastian, Spain, 24–25 May 2000; pp. 1–15.
31. Gullino, A.; Matteis, P.; Aiuto, F.D. Review of Aluminum-to-steel Welding Technologies for Car-body Applications. *Metals* **2019**, *9*, 315. [CrossRef]
32. Balos, S.; Grabulov, V.; Sidjanin, L.; Pantic, M.; Radisavljevic, I. Geometry, Mechanical Properties and Mounting of Perforated Plates for Ballistic Application. *Mater. Des.* **2010**, *31*, 2916–2924. [CrossRef]
33. Radisavljevic, I.; Balos, S.; Nikacevic, M.; Sidjanin, L. Optimization of Geometrical Characteristics of Perforated Plates. *Mater. Des.* **2013**, *49*, 81–89. [CrossRef]
34. Diederen, A.; Broos, J.; Peijen, M. Modern Armour Configurations against 14.5 mm AP. In *Lightweight Armour Systems Symposium, Shrivenham, Proceedings of the Lightweight Armour Systems Symposium, Shrivenham, UK, 28–30 June 1995*; Royal Military College of Science, Shrivenham: Shrivenham, UK, 2006; paper no. 131193.
35. Balos, S. *Perforirane Ploče za Balističku Zaštitu*; Faculty of Technical Sciences: Novi Sad, Serbia, 2015.
36. Hazell, P.J.; Roberson, C.J.; Moutinho, M. The Design of Mosaic Armour: The Influence of Tile Size on Ballistic Performance. *Mater. Des.* **2008**, *29*, 1497–1503. [CrossRef]
37. Balos, S.; Radisavljevic, I.; Rajnovic, D.; Dramicanin, M.; Tabakovic, S.; Eric-Cekic, O.; Sidjanin, L. Geometry, Mechanical and Ballistic Properties of ADI Material Perforated Plates. *Mater. Des.* **2015**, *83*, 66–74. [CrossRef]
38. Balos, S.; Radisavljevic, I.; Rajnovic, D.; Janjatovic, P.; Dramicanin, M.; Eric-Cekic, O.; Sidjanin, L. Ballistic Behaviour of Austempered Compacted Graphite Iron Perforated Plates. *Def. Sci. J.* **2019**, *69*, 571–576. [CrossRef]
39. Balos, S.; Sidjanin, L.; Rajnovic, D. ADI Materials for Ballistic Protection. In Proceedings of the 34th International Conference on Production Engineering, Nis, Serbia, 28–30 September 2011; pp. 91–94.
40. Thomas, D.J. Laser Cut Hole Matrices in Novel Armour Plate Steel for Appliqué Battlefield Vehicle Protection. *Def. Technol.* **2016**, *12*, 351–359. [CrossRef]
41. Balos, S.; Sidjanin, L. Metallographic Study of Non-homogenous Armour Impacted by Armour-piercing Incendiary Ammunition. *Mater. Des.* **2011**, *32*, 4022–4029. [CrossRef]
42. Fras, T.; Faderl, N. Influence of Add-On Perforated Plates on the Protective Performance of Light-Weight Armour Systems. *Probl. Mechatron. Armament Aviat. Saf. Eng.* **2018**, *9*, 31–48. [CrossRef]
43. Fras, T.; Murzyn, A.; Pawlowski, P. Defeat Mechanisms Provided by Slotted Add-on Bainitic Plates against Small-calibre 7.62 mm × 51 AP Projectiles. *Int. J. Impact Eng.* **2017**, *103*, 241–253. [CrossRef]
44. Kiliç, N.; Bedir, S.; Erdik, A.; Ekici, B.; Taşdemirci, A.; Güden, M. Ballistic Behavior of High Hardness Perforated Armor Plates against 7.62mm Armor Piercing Projectile. *Mater. Des.* **2014**, *63*, 427–438. [CrossRef]

45. Kılıç, N.; Ekici, B.; Bedir, S. Optimization of High Hardness Perforated Steel Armor Plates using Finite Element and Response Surface Methods. *Mech. Adv. Mater. Struct.* **2017**, *24*, 615–624. [CrossRef]
46. Mishra, B.; Jena, P.K.; Ramakrishna, B.; Madhu, V.; Bhat, T.B.; Gupta, N.K. Effect of Tempering Temperature, Plate Thickness and Presence of Holes on Ballistic Impact Behavior and ASB Formation of a High Strength Steel. *Int. J. Impact Eng.* **2012**, *44*, 17–28. [CrossRef]
47. Mishra, B.; Ramakrishna, B.; Jena, P.K.; Siva Kumar, K.; Madhu, V.; Gupta, N.K. Experimental Studies on the Effect of Size and Shape of Holes on Damage and Microstructure of High Hardness Armour Steel Plates under Ballistic Impact. *Mater. Des.* **2013**, *43*, 17–24. [CrossRef]
48. Burian, W.; Żochowski, P.; Gmitrzuk, M.; Marcisz, J.; Starczewski, L.; Juszczyk, B.; Magier, M. Protection Effectiveness of Perforated Plates Made of High Strength Steel. *Int. J. Impact Eng.* **2019**, *126*, 27–39. [CrossRef]
49. Cui, T.; Qin, Q.; Yan, W.; Wang, T.; Zhang, J. Ballistic Resistance of Novel Amorphous-Alloy-Reinforced Perforated Armor. *Acta Mech. Solida Sin.* **2021**, *34*, 12–26. [CrossRef]
50. Wang, W.; Dong, C.; Shek, C. Bulk Metallic Glasses. *Mater. Sci. Eng. R Rep.* **2004**, *44*, 45–89. [CrossRef]
51. Schuh, C.A.; Hufnagel, T.C.; Ramamurty, U. Mechanical Behavior of Amorphous Alloys. *Acta Mater.* **2007**, *55*, 4067–4109. [CrossRef]
52. Dai, L.H.; Bai, Y.L. Basic Mechanical Behaviors and Mechanics of Shear Banding in BMGs. *Int. J. Impact Eng.* **2008**, *35*, 704–716. [CrossRef]
53. Johnson, W.L. Bulk Glass-forming Metallic Alloys: Science and Technology. *MRS Bull.* **1999**, *24*, 42–56. [CrossRef]
54. Chao, L.; Kun, L.; Guo, X.J.; Yuan, L.X. Experimental Study on Ballistic Performance for Multi-hole Armor Steel Plates Against the 7.62mm Armor Piercing Projectile. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *382*. [CrossRef]
55. Madhu, V.; Bhat, T.B. Armour Protection and Affordable Protection for Futuristic Combat Vehicles. *Def. Sci. J.* **2011**, *61*, 394–402. [CrossRef]
56. Langdon, G.S.; Nurick, G.N.; Balden, V.H.; Timmis, R.B. Perforated Plates as Passive Mitigation Systems. *Def. Sci. J.* **2008**, *58*, 238–247. [CrossRef]
57. Langdon, G.; Nurick, G.; Du Plessis, N.; Rossiter, I. Using Perforated Plates as a Blast Wave Shielding Technique for Application to Tunnels. *Appl. Mech. Mater.* **2011**, *82*, 467–472. [CrossRef]
58. Ciortan, I.F.; Giurgiu, I.T.; Pupăza, C. Passive Mitigation Solutions using Explicit Dynamics Simulation. *Proc. Rom. Acad. Ser. A Math. Phys. Tech. Sci. Inf. Sci.* **2014**, *15*, 262–271.

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Article

Active Control Parameters Monitoring for Freight Trains, Using Wireless Sensor Network Platform and Internet of Things

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Abstract: Operating in a dynamic and competitive global market, railway companies have realized many years ago that better management of their logistical operations will enhance their strategic positions on the market. The financial component of daily operations is of utmost importance these days and many companies concluded that maximizing the profit relies on the integration of logistical activities with better income management. This paper presents a system consisting of three components: Ferodata BOX, Ferodata MOBILE, and Ferodata SYS, used to transmit to a web-server the status and operating information of an electric or diesel train. Train information includes data from locomotives, wagons, train driver, route, direction, fuel or electric consumption, speed, etc. All this information is processed in real-time and can be viewed in the web-server application. Additionally, the web-server application could manage and report details that are coming from the wagons, such as valuable information regarding the bogie wear, the identification of the wagons attached to a gasket, and identification the situations in which a wagon or group of wagons comes off the gasket configuration. All information about the status of trains is available on-line and at any moment the person responsible for management can use these data in their work.

Keywords: monitoring web server application; railway transport management; connected train; sensor networks; Internet of Things (IoT)

1. Introduction

Following the evolution of optimization techniques, many industries have updated the way they operate, to capitalize on these innovations through achieving better management of their operations [1–5]. In this regard, railway operations consist of a large number of complex related policies, i.e., train arrival/departure schedules, maneuvers and leadings, management of rail fleet, assignment of the locomotives, distribution of available assets, and employee management [6–8]. These are the main reasons why railway transport has always faced difficulties and many of their management tools do not take into account the reality of day-to-day operations. The freight railroad industry offers more efficiency as compared to trucks; this is why International Business Machines Corporation (IBM)

has proposed a wireless sensor network dedicated to monitoring the train parameters, under the name of Sensor Enabled Ambient Intelligent Telemetry (SEAIT) [9].

A wireless sensor network dedicated to monitoring the parameters of the train has two elementary components: the sensor and the communication module. The sensors investigate the physical parameters, such as vibrations [9], temperature [10–12], position, velocity, etc. These parameters are transferred to a data concentrator by various communication protocols, part of these protocols being conceived as dedicated to a specific application [9]. In other situations, standard technologies such as ZigBee or WiFi are recommended [10]. The wireless sensors network is applied also in urban train transportation [12–14] to perform an interchange V2V (vehicle-to-vehicle) or I2V (infrastructure-to-vehicle) [15].

Furthermore, in network hubs, railway transport is more flexible in terms of usage capacity and speed, by comparison with other means of transport [16–18]. Finally, most of the companies are in the process of switching the way they operate from a weight-based approach to an operation-scheduled approach.

RTM (railway transport management) is a planning and monitoring solution for freight railway transport and includes the following main functions:

- Assignment of resources;
- Cart Tracking and Monitoring Module;
- Surveillance of Trains and Carts Optimization Module;
- Extended logging for all users and network actions;
- Complete data history: hour, date, author, IP;
- Complete commercial history for trains and carts.

The RTM main characteristics include (1) platform accessed via the Intranet for inside users and via Internet for selected users; (2) browser access not related to the user operating system and with minimal hardware requirements; (3) mandatory authentication for all users of the application, divided in user groups; (4) tagging of all system interaction information (i.e., system access, transfer of responsibilities among users from one phase to the next one, etc.) and generation of output data in the form of reports/decisions containing the following: system access data, performed action, and responsible person; (5) saving logs for all the activities which interact with the application. Logs will be defined for the actions of introduction, deletion, and modification of data (for modification, monitoring parameters will be set), with a focus on data transfer; (6) dynamic user groups and area for the organization of responsibilities—users will have at least three distinctive roles: user administrator of the application; standard user; user with extended rights (with a role in the data export and report generating).

2. Reliable Automated Test Solutions for V2X, V2V, V2I Communications and IoT

In Europe alone, between 15 and 25 billion euros are spent annually on maintenance and repair work on train and railway infrastructure. Under these conditions, saving only 1% of these costs—the equivalent of 150–250 million euros—could have a significant impact on the business of railway operators [15–17]. Maintenance costs can be reduced by halving the duration of roadside inspections and by reducing the period of incapacitation of the respective route. This would result in a fivefold return on investment as well as a reduction in the risk to maintenance teams. It is clear that the digitization of train transport is in full swing, since it provides a better analysis of the information collected by traditional methods and by connecting more and more sensors on railway equipment to the Digital Platform. Additionally, the effects are huge, the focus being transport safety. How does digitization work if an accident occurs on a section of railway or subway? “One situation could be the detection of a variation in the power consumption of the equipment. When IoT and Big Data recognize a model of performance criteria that has generated problems in the past, analytical information based on this experience will trigger a predictive alert, allowing operators to act as such,” explained by Alain Le Marchand from Thales. Thales already monitors more than 40,000 assets of the UK train network and is working on capabilities similar to Open Lab Initiative (French Railways). More sophisticated

equipment means more valuable information and more efficient and secure services. It is a fiber optic axle counter capable of analyzing the weight of trains and calculating the number of passengers in each train [18].

For several years, automobile manufacturers and government agencies have sought ways to improve safety and effectively manage traffic flow. Wireless communication systems are advancing, and the vision of automobiles talking to each other (V2V) and to roadside units (V2I) is becoming a reality [19–21].

These planned automotive wireless communication systems for vehicle-to-everything (V2X) communications are collectively known as intelligent transportation systems (ITS). The first wave of solutions was based on IEEE 802.11p technology, but now C-V2X solutions based on LTE are appearing, and discussions about how 5G will play a role are already happening [22–25]. Well-established vehicle sensors, e.g., radar sensors, cameras, and tachometers, already provide information about distances to nearby obstacles and about velocities, but sharing information from the vehicle to everything also allows knowledge of critical traffic situations and collisions so that the driver or the car can initiate countermeasures to avoid accidents or create a better traffic flow [26–29].

Vehicle-to-vehicle (V2V) communications systems require a stable wireless link to maximize the throughput of information, which increases driver safety. To ensure a good wireless link, receivers must be able to detect signals even under the worst conditions, e.g., low signal-to-noise ratio (SNR), poor error vector magnitude (EVM), and heavy fading. Replicating these conditions in the lab requires high-performance test equipment capable of generating/analyzing the V2X signals, the required fading conditions, and satellite signals for highly accurate positioning [30–32].

V2V technology is used to perform communication between neighboring devices [33] and it could be useful in railway transport as a backup or redundant solution for GPRS communication. If the GPRS communication fails, the risk of collision is high and in some situations V2V could provide information on train positions, velocities, and trajectories but the distance between the trains must be larger than EBD (emergency braking distance) [33]. Another application of V2V technologies is in the subway where the GPRS is not functional. The energy needed for data acquisition and communication is locally generated by a harvesting circuit that converts the mechanical energy into electrical energy. Unlike other technical solutions found in the literature [34–40], this paper presents an efficient convertor of the rotating movement of the wheel into electrical energy [31]. The information concerning the wagon parameters was sent in a linear mesh routing from the nodes to the data concentrator.

3. Functional Structure of the Wagon Monitoring Web Server Application

The wagon monitoring web server application presented in this paper includes the functional modules presented in Figure 1. Regarding the communication technologies for V2V, it will apply LoRa (long range radio) or NB (narrowband).

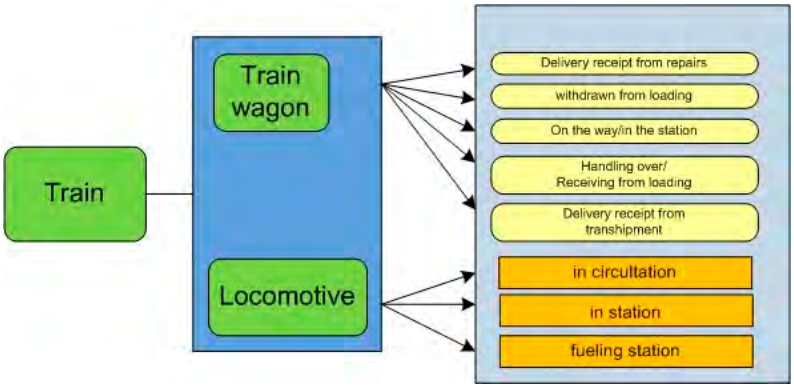
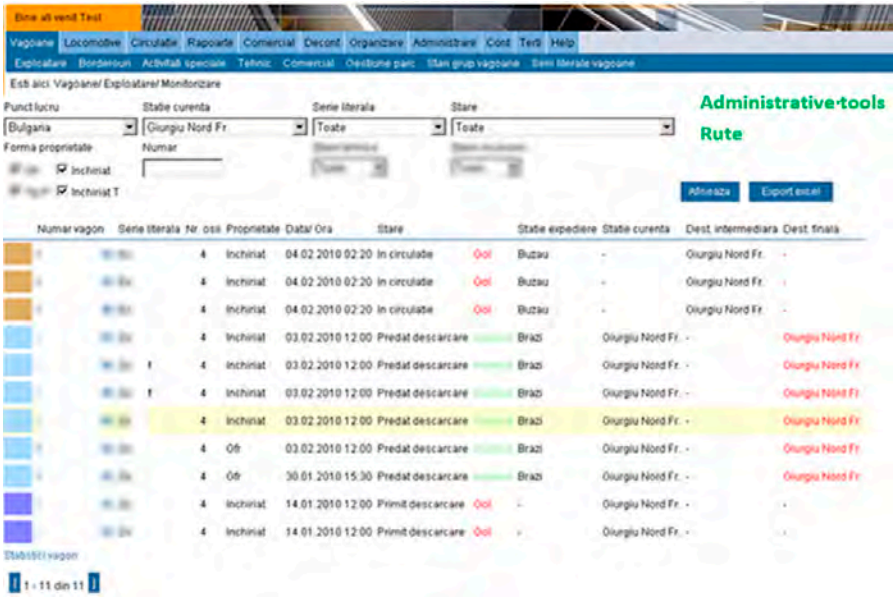


Figure 1. Structure of our platform divided into modules.

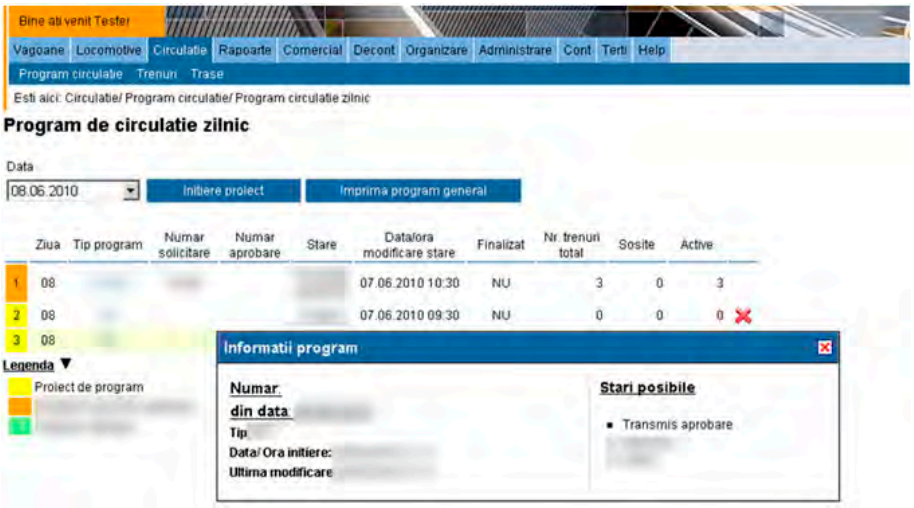
The train wagon management web server application has the following components: locomotive fleet monitoring, in terms of location (current station) and current status (in transit, in a station, refueling,

at a draw, unloading, etc.); commercial history monitoring for each wagon; statistics regarding the status of all wagons; status regarding wagons from each station; operations for individual wagons and wagon groups; status regarding manifests (transport documents); maintenance of the selected databases (wagon malfunctions, commercial issues, components, wagon-manufacturing company, etc.); activities specific to international traffic; special activities: re-sending, re-receiving.

The wagon monitoring web server application (screen captures) is presented in Figure 2a,b. Figure 2a illustrates the train wagon list, with administrative tools such as the ID of wagons, route, reports, cost, help, and one example of train wagon route. Figure 2b presents possible action and general information about the changing status of the train wagon. The user interface of the application is Romanian but we aim to improve this aspect in the future development stage of the application (for data confidentiality the figures are blurred).



(**a**)



(**b**)

Figure 2. Wagon monitoring web server application (screen captures): (**a**) train wagon list; (**b**) changing the status of train wagon; (observation: the user interface of the application is in Romanian but we aim to improve this aspect in the future development stage of the application. For data confidentiality the figures are blurred).

The locomotive management web server application, illustrated in Figure 3 includes the monitoring of the locomotive fleet in terms of location (current station), current status (in motion, in the station, halted, refueling, etc.); the locomotive operations history; deleting/adding new locomotives to the locomotive fleet; the maintenance of locomotive-specific databases: failures, manufacturers, spare parts, roles, attributes, traffic conditions); classification of locomotive series (for data confidentiality the figures are blurred).

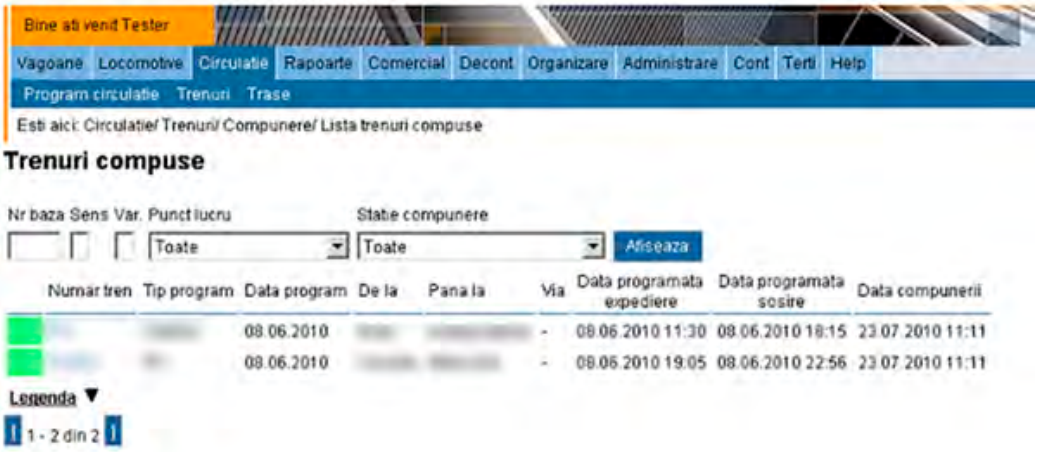
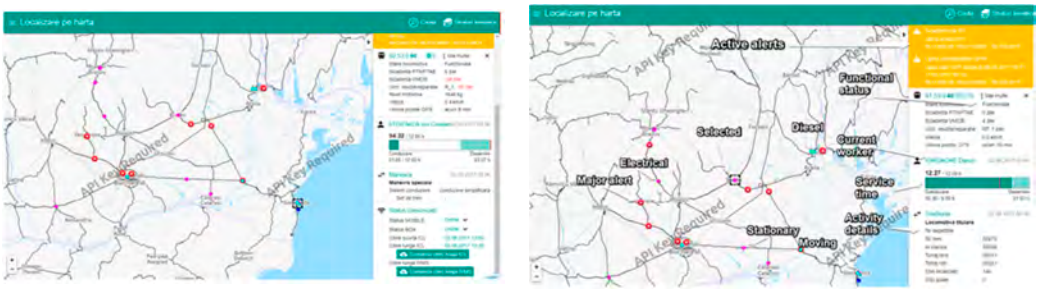


Figure 3. Locomotive management web server application (screen capture): monitoring of train circulation—one example of compound trains, with the date of departure, the date of train composition, the joining of new wagons and the date of arrival. (Observation: the user interface of the application is in Romanian but we aim to improve this aspect in the future development stage of the application. for data confidentiality the figures are blurred).

The web-server application regarding map positioning of train circulation, illustrated in Figure 4a,b, includes the possibility of checking specific booklets that are annually loaded in the application and allow the subsequent devising of the circulation programs by selecting the trains from the booklet; assistance with train programming by providing details regarding the possible transport relations (searches in booklet after "n" points of the itinerary); recording the circulation restrictions in the booklet; devising daily circulation programs; exporting the print version for the daily program; monitoring the status of daily programs.



(**a**) (**b**)

Figure 4. Web-server application regarding map positioning of train circulation (screen captures): (**a**,**b**) monitoring of train position with the map localization details. (Observation: the user interface of the application is in Romanian but we aim to improve this aspect in the future development stage of the application).

The correlated information for train speed, fuel or electricity consumption, and geographical identification is illustrated in Figure 5.

Figure 5. Display in the web-server application of train information, with correlated information for a train, information for DL1 and DL2/DL3, train speed, fuel or electricity consumption, and geographical identification (screen captures). Observation: the user interface of the application is in Romanian but we aim to improve this aspect in the future stage of application development.

4. FERODATA System Architecture

The FERODATA system architecture consists of Ferodata SYS, Ferodata BOX, and Ferodata Mobile, presented in Figure 6a,b. Ferodata SYS is the web-based module accessible at the headquarter and has all the information collected from the locomotive and their operators such as:

(1) Locomotive list: shows the information about the actual position for all locomotives, functional status, the revisions, diesel level, current worker, current activity, current train number, communication status (online/offline);

(2) Map monitoring: illustrates all the locomotives on a map view, showing information about its type, circulation status, direction, speed, alerts, etc.;

(3) Circulation chart with a graphics-based presentation of train circulation on a selected transport relation and period;

(4) Sensor data export allows exporting original data collected from the locomotive sensors (DL1, DL2, DL3) for a selected period and group of locomotives;

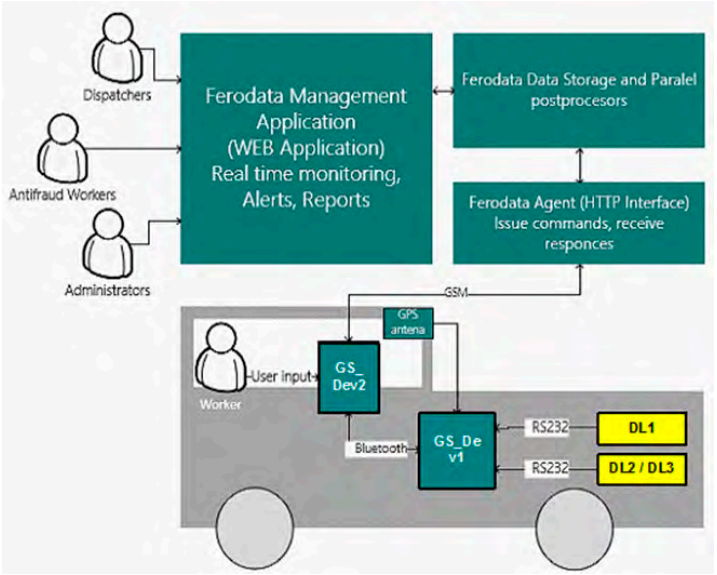
(5) Comprehensive view of all alerts issued by the system (consumption alerts, data unavailability, connection unavailability, etc.).

The Ferodata BOX (GS_Dev1) acquires information of interest (GPS location, fuel/electricity consumption, train speed, alarm situations) and sends them via wireless to a mobile device or tablet using Ferodata Mobile (GS_Dev2).The Ferodata BOX, presented in Figure 6 is a piece of hardware equipment mounted in the locomotive connected to the locomotive sensors IVMS (DL1), ICL (DL2), and CEL (DL3) to collect real-time technical information.

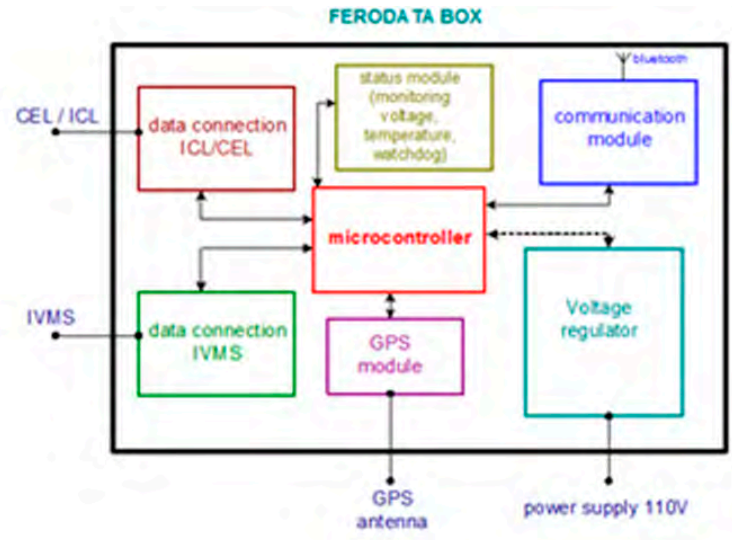
The GPS module collects position information at every 5 s, communicates with Ferodata Mobile; registers GPS coordinates at every 5 s; communicates with Ferodata to send data received from locomotive devices; self-monitoring functions (internal temperature, voltage); reliable in hard conditions (temperature, vibration, humidity).

The Ferodata MOBILE is an Android-based mobile application installed on a tablet that collects data from Ferodata BOX and delivers it to the headquarter via mobile data connection channel. It also collects the activity data reported by locomotive operators. This application is a mobile application, compatible with Android 5 that allows the locomotive mechanic to report its current activity. The application communicates with Ferodata SYS; it receives commands that are sent to Ferodata BOX for execution and sends back responses for previous commands from SYS; communicates

by Bluetooth with Ferodata BOX in order to send commands and receive responses; stores data, using storage until the reliable data connection is available.



(**a**)



(**b**)

Figure 6. FERODATA system architecture: (**a**) Ferodata SYS, Ferodata BOX (GS_Dev1) and Ferodata Mobile (GS_Dev2) and (**b**) block scheme of Ferodata BOX (GS_Dev1) device.

A locomotive is equipped with the SSAMR devices (a device for measuring and recording speed, safety, and awareness) (DL1) and ECR (electric consumption recording) (DL2) or ICL (fuel consumption recording) (DL3). These devices answer to the commands initiated by Ferodata BOX (GS_Dev1) using RS232 protocol. GS_Dev1 interrogates, at certain time intervals, the devices DL1/DL2/DL3 and stores data in a buffer memory. Consequently, the GS_Dev1 device communicates with GS_Dev2 using Bluetooth. GS_Dev2 can initiate the reading of the DL1/DL2/DL3 commands by sending instructions to GS_Dev1, which in turn sends the commands to DL1/DL2/DL3.

The data received from DL1/DL2/DL3 are stored locally in GS_Dev1 and then are sent to GS_Dev2. After the data is received by GS_Dev2 and checked in terms of integrality, a new command is generated to GS_Dev1 to clear the memory buffer.

Data communication between GS_Dev2 and GS_Dev1 is carried out in text mode, using ASCII code, except for the commands used to download certain buffers which will be transmitted in binary mode. In the case of commands/answers with multiple parameters, these parameters will be separated as follows P1 = V1#P2 = V2, where:

- P1 represents the name of parameter 1;
- V1 represents the value of parameter 1;
- P2 represents parameter 2;
- V2 represents the value of parameter 2;
- # represents pair separator of parameter-value type;
- = represents a connecting relationship between parameter name and parameter value;
- *a* maximum of 100 configuration commands in the interval CMD_000–CMD_099.

Some examples of commands are presented in Table 1.

Table 1. Commands.

Command	Description
CMD_000	Reset of device; Parameters: none
CMD_001	Update of query periodicity for device DL1 Parameters: T = 10, T = time in seconds; Output: OK or FAIL; Example: CMD_001:T = 10
CMD_002	Update of query periodicity for device DL3 Parameters: T = 10, T = time in seconds; Output: OK or FAIL Example: CMD_002:T = 10
CMD_003	Update of query periodicity for GPS location Parameters: T = time in seconds; Output: OK or FAIL Example: CMD_003:T = 10
CMD_004	Update of device's internal clock Parameters: T = date and hour specified in the format; Output: OK or FAIL Example: CMD_004:T = 20181218064000
CMD_100	Operational parameters reading GS_Dev1 Parameters: none Output: battery charging level, if it is charging, GPS signal level, Bluetooth signal level, date of last start (restart), internal temperature, status of DL1 connection, status of DL2 connection, status of DL3 connection, date of last DL1 query, date of DL2 query, date of last DL3 query, buffer load (available memory), effects in case of success GS_Dev1—does not exist; DL1—not the case; DL2—not the case; DL3—not the case Example of call: CMD_100
CMD_101	Acquire current GPS position. Executes a reading of the GPS coordinates at the moment of the command Parameters: none Output: OK: latitude, longitude, altitude, precision; FAIL
CMD_102	Acquire GPS position history stored since last data download from the device. It is presumed that GPS data are recorded at set time intervals using the following command: CMD_003 Parameters: none Output: OK: date_hour1, latittude1, longitude1, altitude1, precision1#date_hour2, latitude2, longitude2, altitude2, precision2#; FAIL Shows the case in which a DL1, DL2, DL3 device is not reachable.
CMD_200	Acquire IVMS data Output: binary, to be discussed /suggested Output: DL3#aaaaa#xxxxxxxxxx#bbbb Explanations: aaaaa—number of bytes to be sent bbbbb—CRC16/32 After CMD_200 issues the command and GS_DEV2 successfully receives data from IVMS, GS_DEV2 starts recording 10 h of functioning. After this time, GS_DEV2 starts an alarm which advises the locomotive mechanic to grant a new DL! Reading

The program flow chart implemented in GS_Dev1 is presented in Figure 7. After the start of the circuit and initializing the device parameters (represented by A and B labels) the program is waiting for a command (the list of the commands is presented in Table 1 of this paper), this operation is represented by C label. According with the command message (conditioned through D label), if the command is valid a dedicated block code will be executed (label E), the sensors data will be read, the data will be arranged in data packages (label G), and they will be sent to the GS_Dev2 device (label H).

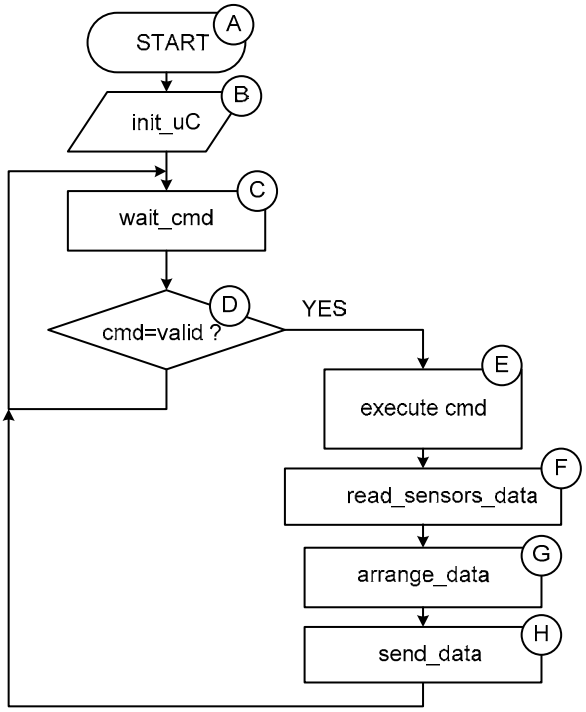


Figure 7. The flow-chart implemented in GS_Dev1 device.

The command post no. 1 of locomotive LDE and the components of the electronic assembly of the device GS_Dev1 are illustrated in Figure 8, as a block scheme. The GS_Dev1 device has four connectors for the connection with GPS antenna, DL1, DL3, and power supply.

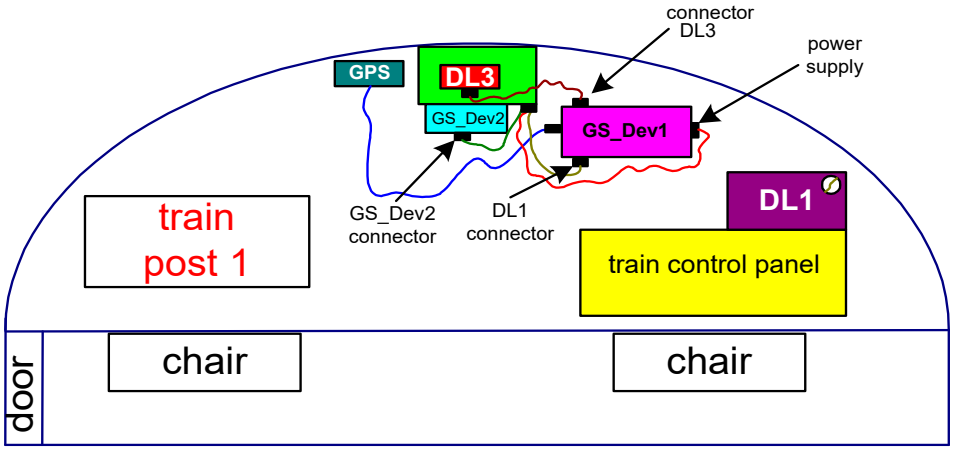


Figure 8. Assembly for GS_Dev1, DL1, DL3 devices and GPS module in the train driver's cabin.

Figure 9 illustrates an upper view of the GS_Dev1 device and the connecting elements with the DL1, DL2, and DL3 devices. The power supply of the GS_Dev1 device can be made from continuous

current (CC): min. 110 V, max. 350 V. (directly from the batteries mounted on the locomotive) or alternative current (AC): min. 80 V RMS, max. 250 V RMS.

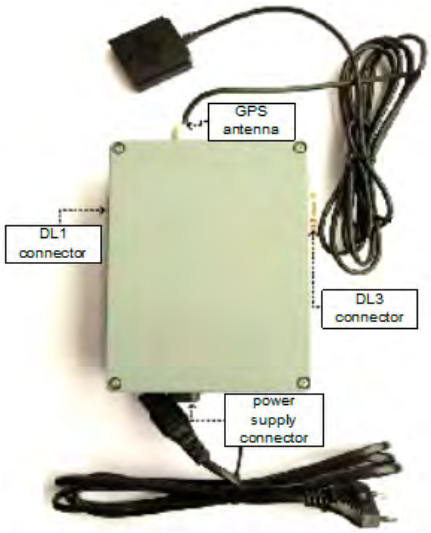


Figure 9. Upper view for the device GS_Dev1.

5. Results

Data monitored in the railway transport system refer to train parameters and railroad parameters [16–19]. This paper presents a system and a method of train wagon parameter monitoring using a wireless sensor network [20–22]. The data generated by the sensors are transmitted to the device GS_Dev1. Parameters monitored by the sensors mounted on the train wagons are speed of the wagon, temperature, geographical location, vibrations, etc. [23,24]. It is also possible to establish the order of the wagon in the lining train [25]. An advantage of this method is the use of an energy harvesting device based on the wagon movement.

We implemented a method and a device dedicated to monitoring the parameters of the wagons by remote data transfer. The wagon's position, speed, and other parameters should be known by the train driver and by the logistics department also [26]. Usually, the connections between the wagons in a trainset are mechanical and pneumatical. The information from the individual wagons could be collected using wireless connectivity.

The issues that arise in such technical challenges are related to the sensors, to the connectivity, and the power supply [31]. The electronic device dedicated to monitoring the wagon parameters (Wag-Pos) consists of an acquisition and processing block AP that gathers the data from a sensor block SB. These data are locally processed, and the information is transferred by several RF communication modules such as RF_up, RF_down, GPRS.

The electronic circuits of the wag_POS module are supplied via an energy block BE which has the role of converting some of the energy resulting from the wagon wheels and vibrations into electrical energy, in order to bring this energy into the optimal parameters of the electronic circuits supply. This role is assumed by an EH harvesting circuit, which stores the energy in a DC storage unit that may be an accumulator or a super-capacitor. The energy resulting from the rotation of the wheels is converted into electricity using an ELM electromagnetic generator (Figure 10).

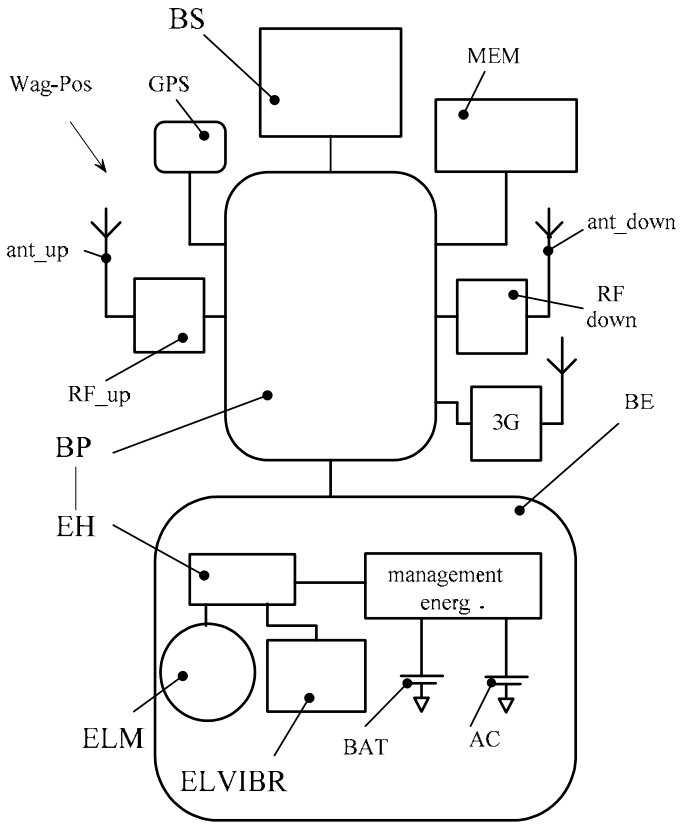


Figure 10. An electronic device dedicated to monitoring the wagon parameters Wag-Pos [31]. (Reproduced with permission from Prof. Adrian Brezulianu, "Wagon Monitoring Method and System," Patent Application RO132982A2, 2018).

Another form of energy that is converted to electrical energy is that resulting from vibrations, the conversion of this energy into electrical energy is done through a piezoelectric or electromagnetic device itself known as ELVIBR. The conversion of the rotation energy in electrical energy is performed according with the technical solution presented in the patent application RO132982A2 [31].

A set of coils are mounted on a radial support (Figure 11), these coils gather the variable magnetic field that is generated by a set of magnets which are mounted on a rotating support that is attached on the wheel-axle of the wagon.

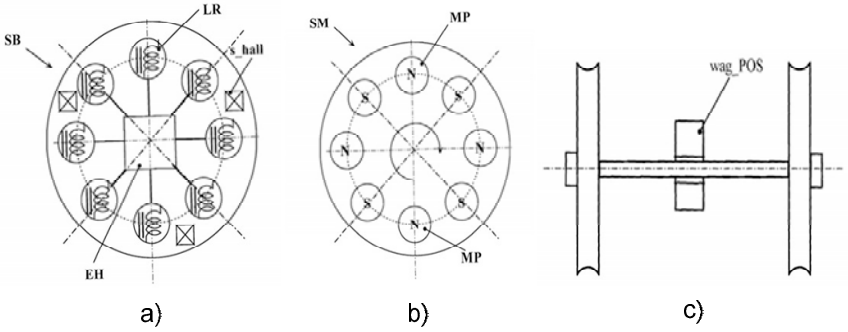


Figure 11. Energy convertor: the coils support (**a**), the magnets support (**b**), and (**c**) the wheel-axle with wag_POS module (Reproduced with permission from Prof. Adrian Brezulianu, "Wagon Monitoring Method and System," Patent Application RO132982A2, 2018 [31]).

The wagon monitoring system is made up of several electronic devices for monitoring the wag_POS_1, wag_POS_2, . . . , wag_POS_n (wagon_POS_n) wagon parameters (Figure 12), which are

mounted on a single wagon w_1, w_{n-1}, . . . , w_n and communicate in a mesh type network in which each device in an n position receives data from a device in an $n-1$ position and sends these data to a device in an $n+1$ position ("up data transmission") or a device in position n receives data from a device in position $n+1$ and transmits these data to a device in position $n-1$ ("down data transmission"). These communication modes are provided with "acknowledge" messages.

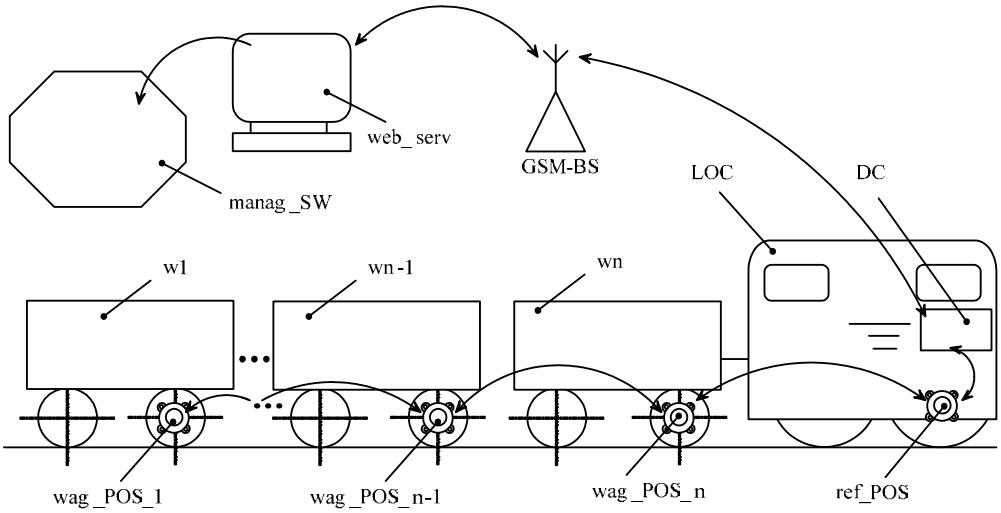


Figure 12. The wagon monitoring system [31]. (Reproduced with permission from Prof. Adrian Brezulianu, "Wagon Monitoring Method and System," Patent Application RO132982A2, 2018).

The data are centralized in the memory of a known CD data hub itself which is mounted on a LOC locomotive from where they are transmitted through a GSM-BS relay to a *web_serv* web-server to be processed by a *manag_SW* management program. The method and system for monitoring the wagons are intended for railway transport companies that need to organize their transport activities. It is necessary to know in real-time what is the configuration of a train lining, to find out the identity of the wagons to be attached to a gasket, to identify the situations in which a wagon or a group of wagons comes off the configuration of the gasket.

The configuration of a moving train gasket is determined by establishing a database of all the wagon IDs that are inscribed in the pos_WAG devices. The scenario is as follows: (a) the data center receives a command to verify the gasket configuration; (b) the data concentrator sends the command to verify the configuration of the gasket to the device in the immediate vicinity, whose index considering it as n, the value of n indicating and the number of wagons of the gasket; (c) the command propagates in the mesh network through each device pos_WAG; (d) each pos_WAG device sends the response through the mesh network to the hub; (e) a comparison is made between the reference database and the database of received IDs. The data routing is performed in a "linear mash routing" [9], one advantage of this method is low power consumption as compared to "probabilistic routing".

The integration of the one-wagon ID into the train kit database is done automatically during the wagon connection. The device of the last gasket wagon sends via the RF_down module a query message that will be received by the RF_up module of the pos_WAG device that is mounted on the wagon to be integrated. Following the query message, this module responds with a message indicating the wagon ID, the last coordinates recorded at the station as well as other parametric records.

When parking a wagon, which is the last wagon of the gasket with the index "1" (pos_WAG_1), the last recorded geographical coordinates that are generated by the GPS module of the *pos_WAG_1* device will be stored in the memory of the device or sent to the network by the data hub, which takes over the geographical coordinates from its GPS module. The condition of parking the wagon is given by the zero speed of the parked wagon while the locomotive speed is different from zero. The monitoring of train parameters using a wireless sensors network (WSN) is supposed to approach

at least two aspects of the practical applications. In SEAIT wireless sensors network three routing models are allowed: probabilistic routing, ad-hoc routing, and linear mesh routing. In our application, we adopted linear mesh routing because for the first two models the communication between the gateway and the nodes is performed individually which means that the gateway (data concentrator) should allocate successive resources to interrogate each node individually. In the case of linear mesh routing the data pass step by step from a node to others and finally are collected in a unique memory location that is situated in *ref_pos* module.

6. Conclusions

This technical solution is dedicated to monitoring the train parameters based on an innovative system that could be adapted to a locomotive as an aftermarket device. The application concept presented in this paper has started from a commercial requirement and all the R&D and production stages are covered. The paper is structured in two sections: the first one approaches the challenges concerning the locomotive parameters (velocity, fuel level, engine rotation, etc.) that are monitored by sensors implemented during the vehicle manufacturing, named FERODATA system. The second section describes a method and a system dedicated to monitoring the wagon parameters: velocity, geographical position, vibration, temperature, etc.). The FERODATA system is implemented in a pilot application consisting of 50 sets of devices that are working on the locomotives in real-time for more than two years, which proves the robustness of this product. It is the first Romanian platform dedicated to monitoring the locomotive parameters in real-time using an aftermarket device.

The Romanian National Railway Safety Authority (ASFR) decided that each locomotive should be equipped with sensors that detect the railways that are occupied, free, or interrupted, the speed limitations imposed on certain sections, the press of the alarm pedal or button. Beside these sensors, a locomotive is also equipped with other sensors that provide information on the average or instantaneous fuel consumption, the tank fuel level, the pressure in the braking system, the thermal engine, and the auxiliary heating system Webasto. All this information is available and can be accessed through a serial communication protocol by the device Ferodata BOX (GS_Dev1). The electronic device we designed, Ferodata BOX, allows the creation of interfaces with other sensors we placed in locomotives: GPS position sensor and radio frequency communication blocks. The latter communicate through a mesh network and collect information from each wagon (wag_POS_n). All the information collected by Ferodata BOX is transmitted by Bluetooth to a mobile intelligent device named Ferodata Mobile—which is a tablet in our case. The train mechanic can also access an application on Android in order to introduce, if necessary, additional information on the train (the name of the train mechanic, the destination, the load, etc.). The information is then forwarded by Ferodata Mobile to Ferodata SYS which manages the database and displays the status of each train. The FERODATA system included Ferodata BOX, Ferodata MOBILE, and Ferodata SYS used to transmit to a web-server the status and operating information of an electric or diesel train. The wagon monitoring method and system describe an innovative technical solution that covers the requirement of gathering parameter data from the freight wagons using a wireless sensors network. The energy needed for data acquisition and communication is locally generated by a harvesting circuit that converts the mechanical energy of the wagon in electrical energy. Unlike other technical solutions found in the literature [30–40], this paper presents an efficient convertor of the rotating movement of the wheel in electrical energy [31]. The information concerning the wagon parameters was sent in a linear mesh routing from the nodes to the data concentrator.

The Romanian train fleet is outdated, and major improvements are unlikely in the short term. This paper presents a solution for managing the information collected from current locomotives and for adding new information necessary for the modern management of a train fleet. The element that has not yet been validated in practice is the information collected from each wagon. The communication between wagons has been emulated in the lab, but it has not been implemented physically on a commercial wagon. This is a valuable element and we intend to validate it practically as soon as

possible, since it collects information from each wagon: speed, pressure in the braking system, the wear and tear of the bogie, the wear and tear of the braking drums, etc.

Future work will include the implementation of an experimental model for the technical solution proposed in the patent application RO132982A2 [31]. We shall also improve the new features of the monitoring system with an updated user interface (English) and extend the applicability for passenger transport. Another research direction is to conceive a communication protocol that will be used in V2V, I2V, I2I, and IoT technologies and that will bring an extra degree of safety in the rail transport.

7. Patents

Brezulianu A., Wagon Monitoring Method and System, Patent Application RO132982A2, Publication Date: 28th December 2018.

Author Contributions: A.B., C.A., M.H., O.G., writing, original draft preparation, designing, analysis, editing. I.C., A.-L.B., and D.-G.B., review, editing, data analysis and investigation. V.E.B., help in methodology investigation, and content verification. A.B. and O.G., supervision, review, content verification, editing, resources and funding acquisition. M.H. and C.A. review and editing the content. All authors contributed to writing, original draft preparation, designing, and analysis, editing. All authors have read and agreed to the published version of the manuscript.

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References

1. Sussman, J.M.; Bronzini, M.S. A Review of: "Perspectives on Intelligent Transportation Systems". *J. Intell. Transp. Syst.* **2006**, *10*, 101–102. [CrossRef]
2. Ghosh, S.; Lee, T.S. *Intelligent Transportation Systems*; Informa UK Limited: Colchester, UK, 2010.
3. Zhou, J.; Chen, C.P.; Chen, L.; Zhao, W. A User-Customizable Urban Traffic Information Collection Method Based on Wireless Sensor Networks. *IEEE Trans. Intell. Transp. Syst.* **2013**, *14*, 1119–1128. [CrossRef]
4. Ishida, K.; Kitabayashi, H.; Nagasu, M.; Bekki, K. New train control and information services utilizing broadband networks. *Hitachi Rev.* **2004**, *53*, 21–24.
5. Ai, B.; Briso-Rodriguez, C.; Cheng, X.; Kürner, T.; Zhong, Z.; Guan, K.; He, R.; Xiong, L.; Matolak, D.W.; Michelson, D.G. Challenges Toward Wireless Communications for High-Speed Railway. *IEEE Trans. Intell. Transp. Syst.* **2014**, *15*, 2143–2158. [CrossRef]
6. Sammouri, W.; Come, E.; Oukhellou, L.; Aknin, P.; Fonlladosa, C.E. Floating train data systems for preventive maintenance: A data mining approach. In Proceedings of the International Conference on Industrial Engineering and Systems Management, Rabat, Morocco, 28–30 October 2013; IEEE: Piscataway, NJ, USA, 2013.
7. Budai-Balke, G. *Operations Research Models for Scheduling Railway Infrastructure Maintenance*; Rozenberg Publishers: Amsterdam, The Netherlands, 2009.
8. Reason, J.M.; Crepaldi, R. Ambient intelligence for freight railroads. *IBM J. Res. Dev.* **2009**, *53*, 6:1–6:14. [CrossRef]
9. Shrestha, P.L.; Hempel, M.; Rakshit, S.; Sharif, H.; Punwani, J.; Stewart, M. Performance Evaluation of Hybrid Technology Networking for Real-Time Monitoring in Freight Railroad Operations. In Proceedings of the 2013 Joint Rail Conference, Knoxville, TN, USA, 15–18 April 2013. [CrossRef]
10. Grudén, M.; Andersson, L.; Zherdev, F.; Dancila, D.; Brunberg, K.; Byström, R.; Hinnemo, M.; Rydberg, A.; Edvinsson, N. Field operational testing for safety improvement of freight trains using wireless monitoring by sensor network. *IET Wirel. Sens. Syst.* **2014**, *4*, 54–60. [CrossRef]
11. Arif, M.; Wang, G.; Geman, O.; Balas, V.; Tao, P.; Brezulianu, A.; Chen, J. SDN-based VANETs, Security Attacks, Applications, and Challenges. *Appl. Sci.* **2020**, *10*, 3217. [CrossRef]

12. Aguirre, E.; López-Iturri, P.; Azpilicueta, L.; Redondo, A.; Astrain, J.J.; Villadangos, J.; Bahillo, A.; Perallos, A.; Falcone, F. Design and Implementation of Context Aware Applications with Wireless Sensor Network Support in Urban Train Transportation Environments. *IEEE Sens. J.* **2016**, *17*, 169–178. [CrossRef]
13. Diez, P.L.; Gabilondo, I.; Alarcon, E.; Moll, F. Mechanical Energy Harvesting Taxonomy for Industrial Environments: Application to the Railway Industry. *IEEE Trans. Intell. Transp. Syst.* **2019**, 1–11. [CrossRef]
14. Briso-Rodríguez, C.; Guan, K.; Xuefeng, Y.; Kürner, T. Wireless Communications in Smart Rail Transportation Systems. *Wirel. Commun. Mob. Comput.* **2017**, *2017*, 1–10. [CrossRef]
15. Wu, J.; Fan, P. A Survey on High Mobility Wireless Communications: Challenges, Opportunities and Solutions. *IEEE Access* **2016**, *4*, 450–476. [CrossRef]
16. Yan, D.; Wang, R.; Liu, E.; Hou, Q. ADMM-based robust beamforming desing for downlink cloud radio access networks. *IEEE Access* **2018**, *6*, 27912–27922. [CrossRef]
17. Peng, M.; Zhang, K. Recent Advances in Fog Radio Access Networks: Performance Analysis and Radio Resource Allocation. *IEEE Access* **2016**, *4*, 5003–5009. [CrossRef]
18. Li, T.; Xiong, K.; Fan, P.; Ben Letaief, K. Service-Oriented Power Allocation for High-Speed Railway Wireless Communications. *IEEE Access* **2017**, *5*, 8343–8356. [CrossRef]
19. Liu, X.; Qiao, D. Location-Fair Beamforming for High Speed Railway Communication Systems. *IEEE Access* **2018**, *6*, 28632–28642. [CrossRef]
20. Ai, B.; Guan, K.; Rupp, M.; Kürner, T.; Cheng, X.; Yin, X.; Wang, Q.; Ma, G.-Y.; Li, Y.; Xiong, L.; et al. Future railway services-oriented mobile communications network. *IEEE Commun. Mag.* **2015**, *53*, 78–85. [CrossRef]
21. Sanguesa, J.A.; Barrachina, J.; Fogue, M.; Garrido, P.; Martinez, F.J.; Cano, J.-C.; Calafate, C.T.; Manzoni, P. Sensing Traffic Density Combining V2V and V2I Wireless Communications. *Sensors* **2015**, *15*, 31794–31810. [CrossRef]
22. Lee, J.; Park, S. Time-Sensitive Network (TSN) Experiment in Sensor-Based Integrated Environment for Autonomous Driving. *Sensors* **2019**, *19*, 1111. [CrossRef]
23. Hodge, V.J.; O'Keefe, S.; Weeks, M.; Moulds, A. Wireless Sensor Networks for Condition Monitoring in the Railway Industry: A Survey. *IEEE Trans. Intell. Transp. Syst.* **2014**, *16*, 1088–1106. [CrossRef]
24. Li, H.; Liu, F.; Hou, Y. Railway Hazardous Articles Monitoring System Based on Wireless Sensor Network. In Proceedings of the 2010 2nd International Conference on Information Engineering and Computer Science, Wuhan, China, 25–26 December 2010; Institute of Electrical and Electronics Engineers (IEEE): Piscataway, NJ, USA, 2010; pp. 1–4.
25. Saghir, H.; Heddebaut, M.; Elbahhar, F.; Rouvaen, J.-M.; Menhaj-Rivenq, A.; Ghys, J.-P. Train-to-wayside wireless communication in tunnel using ultra-wide-band and time reversal. *Transp. Res. Part C* **2009**, *17*, 81–97. [CrossRef]
26. Zhang, C.; Fan, P.; Xiong, K. Optimal power allocation with deley constraint for signal transmission from a moving train to base station in high-speed railway scenarios. *IEEE Trans. Veh.* **2015**, *64*, 5775–5788. [CrossRef]
27. Schoen, R.; Habetler, T.; Kamran, F.; Bartfield, R. Motor bearing damage detection using stator current monitoring. *IEEE Trans. Ind. Appl.* **1995**, *31*, 1274–1279. [CrossRef]
28. Tubaishat, M.; Zhuang, P.; Qi, Q.; Shang, Y. Wireless sensor networks in intelligent transportation systems. *Wirel. Commun. Mob. Comput.* **2009**, *9*, 287–302. [CrossRef]
29. Christidis, K.; Devetsikiotis, M. Blockchain and Smart Contacts for the Internet of Things. *IEEE Access* **2016**, *4*, 2292–2303. [CrossRef]
30. Liu, P.; Ai, B.; Zhong, Z.; Zhou, X. A Novel Train-to-Train Communication Model Design Based on Multihop in High-Speed Railway. *Int. J. Antennas Propag.* **2012**, *2012*, 1–9. [CrossRef]
31. Brezulianu, A. Wagon Monitoring Method and System. Patent Application RO132982A2, 28 December 2018.
32. Wu, Y.; Qiu, B.; Wei, Z.; Weng, J. *Secure Subway Train-to-Train Communications via GSM-R Communication Systems*; Institute of Electrical and Electronics Engineers (IEEE): Piscataway, NJ, USA, 2016; pp. 1–5.
33. Bin, S.; Sun, G. Optimal Energy Resources Allocation Method of Wireless Sensor Networks for Intelligent Railway Systems. *Sensors* **2020**, *20*, 482. [CrossRef]
34. Jiang, C.; Xu, Y.; Wen, C.; Chen, D. Anti-Runaway Prevention System with Wireless Sensors for Intelligent Track Skates at Railway Stations. *Sensors* **2017**, *17*, 2955. [CrossRef]
35. Cañete, E.; Chen, J.; Díaz, M.; Llopis, L.; Reyna, A.; Rubio, B. Using Wireless Sensor Networks and Trains as Data Mules to Monitor Slab Track Infrastructures. *Sensors* **2015**, *15*, 15101–15126. [CrossRef]

36. Cañete, E.; Chen, J.; Díaz, M.; Llopis, L.; Rubio, B. Sensor4PRI: A Sensor Platform for the Protection of Railway Infrastructures. *Sensors* **2015**, *15*, 4996–5019. [CrossRef]
37. Fraga-Lamas, P.; Fernández-Caramés, T.; Castedo, L. Towards the Internet of Smart Trains: A Review on Industrial IoT-Connected Railways. *Sensors* **2017**, *17*, 1457. [CrossRef]
38. Kim, H.; Kim, T. Vehicle-to-Vehicle (V2V) Message Content Plausibility Check for Platoons through Low-Power Beaconing. *Sensors* **2019**, *19*, 5493. [CrossRef] [PubMed]
39. Liu, L.; Song, D.; Geng, Z.; Zheng, Z. A Real-Time Fault Early Warning Method for a High-Speed EMU Axle Box Bearing. *Sensors* **2020**, *20*, 823. [CrossRef] [PubMed]
40. Wang, H.; Chang, L.; Markine, V. Structural Health Monitoring of Railway Transition Zones Using Satellite Radar Data. *Sensors* **2018**, *18*, 413. [CrossRef]

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CONTENT

Ethics of Nuclear Weapons and National Security Intelligence

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for Presentation to the International Ethics Section of the ISA,
San Francisco, April 6, 2013

Introduction

From the beginning of the nuclear age there have been fears that we may have invented a weapon that will destroy us all. J. Robert Oppenheimer, who helped build the first fission bombs, commented often on this (1). Albert Einstein, whose letter to then President Franklin Roosevelt helped convince him to fund them, talked about the imperative to seek peace and new ways of thinking about everything as he neared death (2). Bertrand Russell coauthored a Manifesto with Einstein (and nine others) to warn the world that everything had changed (3). Yet thousands of thoughtful people still felt compelled by the urgencies of World War II to make nuclear weapons and to use two of them against other human beings. To end the war, they said to each other, and perhaps to show the Soviets who would be the big dog following.

But then what?

Another arms race had begun, and bigger, worse WMDs would be developed soon.

As soon as more than one nation had nuclear weapons, some strategy had to be conceived for their use. Mutual Assured Destruction was the main result, and millions learned the irony of a "MAD" strategy, where safety was to be assured by capabilities and declared will to destroy human civilization if we were frightened enough by any enemy. Those we terrified produced similar weapons and strategies. Herman Kahn and colleagues wrote books like "Thinking the Unthinkable" (4) to explain this theory to lay publics unanointed by the priesthood of nuclear physicists. Many nominally good people were hired to build thousands of nuclear warheads and delivery

systems. Thousands more were trained to use them to blow up half of the world if so ordered. Their reliability was tested relentlessly, to pull the trigger or push the button if so ordered, and our bureaucracies learned how to exclude anyone who might hesitate if their duty called. Our adversaries did the same. We shared the lethal technologies with some allies, as did they. And retired nuclear physicists started a magazine, called the Bulletin of the Atomic Scientists, to warn people basically not to do what they had done.

Later we invented modern biological weapons, ever so secretly, and a new community of biologists and doctors learned to sin like physicists[1]. And chemical weapons were 'improved' by development of modern, binary nerve agents, and much more effective than old mustard gas, Zyklon B and such, despite strict prohibitions that were rationalized around. Scientists and intelligentsia pondered how we had wandered into this thicket of moral conundrums. Meanwhile we stumbled on, driven by something. One purpose of this paper is explaining that.

Mutually Assured Destruction (MAD) and the NPT of 1970

This paper assumes the reader has a general awareness of the history of nuclear weapons, of related arms control efforts and of the reasons and rationalizations associated with each. The core will be how and why national security intelligence cultures that study worst case scenarios daily almost inevitably abandon any concept of virtue ethics or deontological frameworks to arrive at utilitarian suicide scenarios like MAD implies. That occurs in the next section.

Here I will highlight two elements of the most important strategic decisions and treaties that seem essential for the educated reader to grasp how so many very intelligent, even brilliant men and some women went from deep commitments to protecting others to equally firm commitments to murder millions should the proper order be received. They still do today. It helps to recognize that weapons of mass destruction were not invented,

[1] "In some sort of crude sense, which no vulgarity, no humor, no overstatement can quite extinguish, the physicists have known sin; and this is a knowledge they cannot lose." J. Robert Oppenheimer, in his Arthur D. Little Memorial lecture at MIT of November 25, 1947, "Physics in the Contemporary World." Biologists have since learned that no matter what "mainstream" biologists proclaim in ethical manifestos, if a government wants to hire someone to work on bioweapons, they will find employees who, once in their top-secret, security cleared cocoons, will do their jobs.

perfected, built or used by people who were intrinsically evil. WMDs were invented, built and used by people who thought they were doing a good thing for their communities. One key word in this process is "bureaucracy" and another is "propaganda" especially internal propaganda.

Wikipedia tells us that "The strategy of Mutually Assured Destruction and the acronym MAD are due to John von Neumann (1902–1957), who had a taste for humorous acronyms. … He was, among other things, the inventor of game theory, a cold war strategist, and chairman of the ICBM Committee until his death in 1957." Game theory is a branch of mathematics fused with ideas about human behavior, and it is very useful in various areas. It also has two embedded assumptions that are the equivalents of Achilles' heels.

The first is that people are "rational actors" and will mostly make "rational" decisions (a.k.a. rational according to the mathematician, physicist or economist positing this). This is called the "rational actor assumption." The problem here is that the concept "rational" varies dramatically across cultures and time, and whatever your concept of rational is, it often degrades under the intense pressures of international crises (5). Besides which, no matter how nice and rational your king or commanders are today, they can go nuts over time or under pressure, both of which have occurred many times in human history. Statistics assure us that if even a tiny probability exists for general thermonuclear war and the paradigm does not change, then it will eventually occur. What is rational about wiring the world for self-destruction on that day?

The second big assumption in MAD theory is that people make all the relevant decisions in this system. Partly true, but not 100%. Many computers are involved in "decision support" during nuclear crises, because the minutes available for a life-or-death-for-the-world decision are very few. Computers make mistakes even if their programmers have been perfect which they never are. Furthermore many of those machines attached to nuclear systems, early warning, and decision support were made decades ago. More important, bureaucracies decide who sits in missile silos or has their hand on nuclear triggers in submarines and such. Bureaucracies have no morals, and national security bureaucracies in particular are afraid of people with deep objections to war, including nuclear holocaust. So they get rid of such people by forbidding their entry into the cloistered worlds of high security clearances (6). Thus isolated, the morally blind then think that they see brilliantly. Finally, corporations are involved, and they respond to one thing only.

One rational response to a world where hegemons have nuclear weapons and are almost constantly waging wars against somebody (a.k.a. the world today) is for smaller nations to get nuclear weapons of their own to avoid becoming targets. Yet today a vast majority of Americans consider Iran and especially North Korea to be literally insane for seeking nuclear weapons (the latter) or weapons capability (the former). Both have been threatened many times by nuclear powers, yet both are condemned for responding in kind by people who have nuclear weapons of their own they would not give up to get into heaven.

The architect of the policy of "containment" so essential to the ability of the Soviet Union to break up without blowing up was George Kennan of the U. S. State Department. On retirement he contemplated these dilemmas very deeply, and he wrote a forward to another deep thinker's book called "The Pathologies of Power" (7, 1987). Kennan wrote:

"All of these men [Albert Einstein, Bertrand Russell, General Douglas MacArthur and President Dwight Eisenhower] perceived the suicidal quality of the nuclear weapon and the danger in allowing it to become the basis of defense postures and the object of international competition. All of them spoke with a great sense of urgency. All went to their deaths hoping, surely, that their warnings would not fall on deaf ears and that a new generation of leaders would recognize that we were all living in a world of new political-strategic realities and would draw the necessary conclusions.

Unfortunately, this has not happened. For thirty years past these warning voices have been disregarded in every conceivable respect. There has been no new mindset. There has been no recognition of the revolutionary uniqueness of the weapons of mass destruction, no recognition of their sterility as weapons, no recognition of the dangers of their unlimited development. On the contrary, the nuclear explosive has come to be treated as just another weapon, vastly superior to others, of course, in the capacity for indiscriminate destruction, but subject to the same rules and conventions that had governed conventional weaponry and its uses in past ages. The suicidal quality of these devices has been ignored."

What Kennan knew but did not write here is that tons of money was being made by bureaucracies and companies building, storing and managing such weapons. Bureaucracies and corporations feed on money not morality. Moral people inside or outside can say whatever they like, but all that talk will have less impact on a bureaucracy or company than budget decisions.

Mindful of such dilemmas, international leaders created a Treaty on the Non-Proliferation of Nuclear Weapons or the NPT (Non-Proliferation Treaty) in 1970 (8). More countries have ratified this treaty (190) than any other arms limitation or disarmament agreement, a testament to its significance. On the other hand, some of the most important nuclear weapons states are not members of the NPT, and the biggest nuclear powers are in clear violation of it. The essential deal was that non-nuclear weapons states would forego building these WMDs in return for help developing nuclear power and a pledge from the nuclear weapons nations to work diligently toward a world without nuclear weapons at all. That part is called Article 6, and we are nowhere near zero nukes 43 years later, which is a big reason why countries like Iran and North Korea are saying forget you pious hypocrites; we're building weapons or capability too.

The Lens of National Security Intelligence and Worst Case Scenarios

National security intelligence organizations do many things, but job #1 is always protecting the government that sponsors them against enemies foreign and domestic, however that may be phrased. This requires sober assessments of the worst things that could happen to a country or a government. History provides many examples of governments that are not here anymore (and even a few whole peoples) because intelligence systems failed at this main task.

Focusing attention every day on the very worst things people can do to each other puts a strain on anyone. Topics can be depressing, responsibilities are great, and workloads heavy. No one wants to be surprised by a new weapon or enemy. But enemies can be masters of deception, and one thing you can count on is that they will be trying to penetrate your organization. So secrecy is the norm, and half of your security officers may be looking for the spy within (9).

Weapons of mass destruction in general and nuclear weapons in particular raise the possibility that small states, or even an individual angry or ideologically committed man, could wreck great havoc on the nations that security officers are determined to protect. So a common way of preparing or training officers is to study worst case scenarios *ad nauseum*, and to assume that anyone, anyone at all might be a spy with deadly capabilities. That dent's mental tranquility.

An example is the "ticking time bomb" category of moral dilemmas, much used in the training of intelligence officers. A common version goes like this: Assume you have caught a terrorist who has planted a nuclear weapon somewhere in your city. It is set to go off soon, but you have some time to interrogate him or her. Do you torture them to try to find out where the bomb is so that it can be defused?

Extreme cases like that often cause people to throw out rulebooks of restraints on the grounds that all those innocents who might die otherwise deserve to be protected "by any means necessary." This is independent of the utility or disutility of torture as an interrogation technique (it is not very good). When you throw out the rulebook you have thrown out deontological ethics, and much or all of international law (10). Even the meaning of "virtue" can be transformed, as when the virtues of restraint and prudence among warriors are overcome by virtues of "courage" to face "hard choices" where the sacrifice of innocents is too often allowed to serve some allegedly greater good. In fact, all you are left with is law of the jungle or act utilitarian ethics that can be used to justify anything if your scenario is extreme enough.

Further complicating things is the verifiable fact that security clearance systems keep out people so moral they would never agree to keep any secret no matter how vile. When agencies ask you to keep secrets, they don't say only some. Gentle folk who decline to promise to keep every secret, even evil ones will not be on any analysis team looking for enemies or operations squad waiting for targets to capture or kill. Compartmentalization enables evil especially well.

The people who remain "cleared" will focus on their positive duties to protect their own (colleagues and sponsors, mothers and children, friends and country). All are at risk to WMDs. And "terrorists" with WMDs are alleged to be extra-special scary since they don't wear uniforms and are allegedly as single-minded about killing you as you can become about killing them.

Such environments are extremely conducive to organizational paranoia and a long list of other failures. One of the most frequent concerns I have heard in over 25 years of studying spies has been not to forget the many very good people who enter such systems and work honestly, diligently, and as ethically as they are allowed to serve real goods – like the safety of their countries and their peoples. Such sources are almost always

frustrated with dysfunctions in their systems, but remain loyal to the causes that led them to enter the world of espionage. Therefore I will spend some space here reviewing a sampler of their memoirs, both critical and nostalgic.

Because there are hundreds of intelligence agencies on earth, a comparative review is impractical in this space although we have done some for special issues of "Intelligence and National Security" among others (11). So we will focus on the CIA here. We begin with insider memoirs that are critical, followed by memoirs that are mainly supportive, followed by a few scathing critiques from outsiders who took time to really understand their topics.

"Ishmael Jones" (an alias) wrote "The Human Factor: Inside the CIA's Dysfunctional Intelligence Culture" in 2008, updated 2010, to explain how getting around the bureaucracy was essential to him becoming one of their most productive case officers (12). "Anonymous" (now known to be Michael Scheuer from the Bin Laden desk at CIA) wrote "Imperial Hubris: Why the West is Losing the War on Terror" in 2004 (13) to explain how the bureaucracy frustrated actually getting Osama Bin Laden, their principal target. We have been assured that Bin Laden was actually killed in 2011 (without, I must note, any forensic evidence presented to external critics) but Scheuer maintains that he could have been killed or captured many years earlier. External critics point out that Bin Laden was worth many billions every year to the institutions seeking him so long as he was alive and free. 2004 also brought us "Denial and Deception: An Insider's View of the CIA from Iran-Contra to 9/11" (14) by Melissa Mahle (a career case officer focused on Middle East nations) to "highlight what is for many, the greatest political scandal of a generation: the failure of the U. S. intelligence community to combat the threat posed by Islamic extremists and prevent the 9/11 attacks." Her book was redacted while in press by the CIA Publications Review Board, after already reviewed and approved, and Mahle was prevented from giving a speech at a conference on ethics for spies where I met her in 2006. Another career officer who became the Chief of the Moscow station, Burton Gerber, was allowed to speak and co-edited a more academic review of dysfunctions and possible fixes in 2005 with Jennifer Sims from Georgetown, "Transforming U.S. Intelligence" (15). Robert Baer, the career CIA officer whom the movie "Syriana" was modeled on, wrote "Sleeping With the Devil: How Washington Sold Our Soul for Saudi Crude" in 2003 (16). As noted before, none of these people are enemies of the US, of the CIA, or of espionage as a profession. They want to improve the

profession by injecting some ethics into it, and reducing the pervasive dysfunctions of the organizations they know quite well. As noted earlier (5) it turns out that the bureaucracies are at the very least allergic to genuine ethics if not outright hostile to them (17).

Long before these authors the former Chief of CIA's Angola Task Force wrote "In Search of Enemies: A CIA Story" in 1978, where he described how the CIA was tasked to destabilize Angola in preparation for the next war (18). And the "first book that the U.S. government ever went to court to censor before publication" (The CIA and the Cult of Intelligence) may have been the most insightful. This was written in 1974 by Vincent Marchetti (who rose to be executive assistant to the Deputy Director of CIA) and John Marks from the State Department's intelligence bureau (19). Their point was simple but powerful: something in the intelligence world had cult-like qualities, and induced cult-like behaviors among people who stayed there. I will simplify that here by asserting that an obsession with secrecy and deep fears of actual ethics among the bureaucracies are the core dysfunctions that enable all the others.

Now for some more positive memoirs. As one might expect, Directors of agencies have more positive views of their decisions under difficult circumstances and of compromises they "must" make with the political leaders who ultimately are their bosses and control their budgets. George Tenet provides a good example of that genre, in "At the Center of the Storm: My Years at the CIA" published in 2007 (20). He saw little wrong that needs fixing; maybe a tweak or two here and there, despite his most notorious failures, 9/11 and the WMD fiasco in Iraq. William Odom, former Army General and then Director of the National Security Agency saw lots to improve but was still fundamentally supportive of the U.S. intelligence community in "Fixing Intelligence for a More Secure America" in 1997 (21). And two books from 2004 present views on how to improve things from two career CIA officers, William Daugherty who was held hostage in Iran for over a year in 1979-80 ("Executive Secrets: Covert Action and the Presidency," 22) and Arthur Hulnick who served the CIA as both an analyst and an operator for 40 years and before that was an Air Force intelligence officer ("Keeping us Safe: Secret Intelligence and Homeland Security," 23).From 2012 come "The Art of Intelligence: Lessons Learned from a Life in the CIA's Clandestine Service" by Henry A. Crumpton (24) who organized the fantastically successful takedown of Afghanistan by CIA and U.S. Special Forces, and "Hard Measures: How Aggressive CIA Actions After 9/11 Saved American Lives" by Jose A. Rodriguez Jr. (who led the agency's descent into depravity by using torture

instead of better methods of interrogation, and seducing 54 other nations on earth to help in various ways, 25).

"Politicization" of intelligence is a recurring problem that all of these authors have seen and many have rebelled against. This basically means when political leaders cause intelligence assessments to be altered to conform to their own desires or prejudices. That can lead to horrible consequences (as when top leaders want to attack someone regardless of facts, or go insane and drive their countries into disaster or destruction in other ways). So all responsible intelligence schools teach analysts to avoid such politicization … if they can! The core problem is that leaders or their policy staff can often fire the analysts, or just ignore the ones they don't like in favor of those who tell them what they want to hear (the sycophant problem). So I will mention here two exceptional books that try to address politicization, Joshua Rovner's "Fixing the Facts: National Security and the Politics of Intelligence" from 2011 (26) and Robert David Steele's 2000 work, "On Intelligence: Spies and Secrecy in an Open World" (27). Steele was a persistent proponent of better use of open sources, and a critic of bureaucratic idiocies, which earned him many enemies among former Marine and CIA colleagues. As you might infer, politicization and protection of budgets is a big problem everywhere. The informal Dean of positive responses to horrible, complicated problems in this domain is probably Loch Johnson whose 2012 book "National Security Intelligence" should be required reading for all young officers-to-be (28). Johnson is a genuine world expert on oversight, and thinks it works better than I do.

Remember, all of these books cited from 11-26 were written by people with very high security clearances who spent years and usually decades working for U. S. intelligence agencies, or in Johnson's case for the U. S. Senate Intelligence Oversight Committee (he is now an emeritus professor at the University of Georgia and senior editor of "Intelligence and National Security"). Now a word or two from critics less constrained.

"The CIA: A Forgotten History" by William Blum, 1986, listed U. S. interventions since World War II with an emphasis on covert wars and coups sponsored secretly by the CIA. It is NOT recommended to young agency officers-in-training (29). "The 'Terrorism' Industry" by Edward Herman and Gerry O'Sullivan (1989, 30) lays out how the Western media were co-opted into supporting such foreign adventures, and cooperating in cover-ups regarding who was really responsible. "Body of Secrets: Anatomy of the Ultra-Secret National Security Agency" by James Bamford, (2001, 31) showed how the other behemoth of America's now 17 intelligence

agencies was involved in such operations. But his book could not show how the NSA would morph after September 11, 2001 into an agency that routinely intercepts and inspects most communications coming into and out of the U.S.A. and a significant fraction of all domestic traffic also. These are split off from telecom company routers and run through supercomputers searching for people saying naughty things. But how would have to wait for a two year Washington Post investigation called "Top Secret America" by its lead author Dana Priest (32). Frank Rich's 2006 expose, "The Greatest Story Ever SOLD: The Decline and Fall of Truth in Bush's America" (33) proves beyond shadow of doubt that the second war against Iraq, begun March 19, 2003, was promoted by flagrantly false and sometime outright fraudulent "intelligence" (making this an international war crime). And finally, another career New York Times reporter and Pulitzer Prize Winner Tim Weiner wrote "Legacy of Ashes: the History of the CIA" in 2007 (34). Taken together, these expose's incinerate the public relations picture of American intelligence which explains why the wall of "national security secrecy" is so essential to the continued budgets of at least the CIA if not the entire U.S. intelligence community which becomes complicit in the murder of innocents when things go really bad. But what about all those good people who enter these dysfunctional systems trying to protect their neighbors from evil abroad?

Well it is very hard on them to be blunt. Not as hard on them as on the people they help to kill, but hard nonetheless. If they retain their consciences, which is difficult if you stay inside too long and use "tradecraft" that has other unhealthy consequences, they suffer astronomic rates of alcoholism and divorce, for example. But this is an essay on the ethics of weapons of mass destruction, so we will return to that focus having established some critical constraints on the institutions that tell U.S. Presidents who to target with nuclear or other "special" weapons.

Iran, Israel, North Korea and the U.S.A. in 2013 as illustrative cases

The hottest issues on America's nuclear security agenda these days are what to do about North Korea (which has a few very primitive nukes, but limited means to deploy them) and Iran (which almost certainly does not have any actual nuclear weapons, and cannot for years, but does have much better missiles than North Korea, and connections with angry people who know how to smuggle things). Regardless of dysfunctions, lack of ethics or any other problems, it will be up to America's intelligence community to

inform our national security commands what Iran and North Korea are up to in every respect, and to recommend options for action if asked.

Vastly complicated this is our very close ally Israel, which has many more and much better nuclear weapons and delivery systems than either Iran or North Korea, partly because they stole the necessary material from America back in 1968 (another story, best left untold here). Israel is also one of the nuclear nations that have not signed the Nuclear Nonproliferation Treaty, so it is harder to determine exactly what their capabilities are. Their intentions are pretty clear – they feel surrounded by enemies and are haunted by the Holocaust (Shoah) so they are determined to avoid genocide, and have worst cases on their minds all the time. Israel also has one of the highest quality human intelligence organizations in the world in the MOSSAD, which is understandably focused on declared enemies like Iran. We depend on them for much of our human intelligence in that area, which makes America vulnerable to manipulation, a common problem with liaison relationships in intelligence. Iran knows that Israel could turn it into bubbling glass if frightened enough, which probably has something to do with the desire among 'hard liners' in Iran for similar weapons. It is MAD squared there.

Iran's top Ayatollah (and supreme leader) Ali Khamenei, has often said that nuclear weapons are immoral and therefore not allowed by Islamic law. But current President Mahmoud Ahmadinejad foams at the mouth about Israel often enough to scare anyone who listens. Those who live in the "worst case scenario" world must assume that Iran could have nuclear weapons soon even if they don't now, and that even if the chief preacher says it's sinful, some generals might have other plans. Plus who knows the future? Worst case analysis assumes worst cases, and WMDs bring out the worst in everyone. We will presume here that you are familiar with the charming reputation of North Korea among its neighbors, and the legacy of dictators leading to the current Kim Jung Un. He may be a breath of fresh air compared to his grandfather and father; we shall see. But it should be noted that third generation dictators tend to be shaky and unpredictable compared with the ones who built their starving nation, perhaps the most brutal police state on earth today. As in each of the other three countries, dear leader Kim must also contend with secret powers behind his throne that can be as evil as anyone publicly visible.

What is a U.S. President to do with this conundrum?

A genuine and certified moral leader, the Nobel Peace Prize winning Rev. Desmond Tutu of South Africa says clearly "We cannot intimidate others into behaving well when we ourselves are misbehaving. Yet that is precisely what nations armed with nuclear weapons hope to do by censuring North Korea for its nuclear tests and sounding alarm bells over Iran's pursuit of enriched uranium. According to their logic, a select few nations can ensure the security of all by having the capacity to destroy all. Until we overcome this double standard – until we accept that nuclear weapons are abhorrent and a grave danger no matter who possesses them – we are unlikely to make meaningful progress in halting the spread of these monstrous devices, let alone banishing them from national arsenals" (35).

Unfortunately, national security intelligence professionals are notoriously indifferent to what preachers say, no matter how many medals they have. They're not "cleared" so presumably don't know much. So we might turn to a former CIA counter-proliferation case officer Valerie Plame Wilson, who wrote on the same day: "Twenty-five years ago, President Reagan laid out a vision for a world without nuclear weapons, and in his first term President Obama boldly picked up that mantle - most famously in his 2009 speech in Prague, where he announced America's commitment to eliminate all nuclear weapons globally. There is now a unique opportunity for President Obama, in his second term, to follow through on that commitment and set the world's course to global zero. He can do this by pursuing further reductions to the United States' and Russia's massive Cold War arsenals and bringing other key countries to the table for the first multilateral nuclear arms negotiations in history." The "Global Zero" campaign Ms. Wilson is supporting "includes a letter to the president from approximately 75 former prime ministers, foreign and defense ministers and military commanders; an official declaration recently adopted by the European Parliament in support of Global Zero's step-by-step plan to eliminate nuclear weapons; and a grassroots petition appealing directly to the president" (36).

So their view is clear – Get rid of the evil things. But could a nation as terrified as Israel ever possibly be persuaded to "get rid of" its most powerful weapons? And what about the U.S.A. which invented them? We can't put a leash on handguns here, much less WMDs. People love them (many people anyway). There seems to be a genuine paradox at play, where the most powerful are the most reluctant to part with weapons, even while

they insist that others around them do. In fact, the most powerful often appear to be the most paranoid as well if you read and listen to what they say. There are few consensuses in this arena, but most observers would agree that if anyone is going to "give up" nuclear weapons, it will have to be everyone, accomplished very slowly, with the most extensive oversight that people can create. The Comprehensive (nuclear) Test Ban Treaty would be a good case to contemplate for guidance on that.

It bears recollection that several countries actually have possessed nuclear weapons yet deliberately got rid of them when wisdom dawned. South Africa had six, or so, and Kazakhstan, Belarus and Ukraine had hundreds each, but were persuaded to turn them over to the Russian Federation as the Soviet Union unraveled. None of those nations was subsequently destroyed.

What is true for nuclear weapons has parallels among chemical and biological weapons. Each is attractive to the worst case mind, and to those who need "enemies" for various reasons. But substantial restraints have been put on all these WMDs when larger publics that sponsored them woke up to the catastrophic consequences should they ever be used. They had to wake up, and they had to penetrate the secrecy barriers that enabled those who need enemies to create and stockpile them. Then they had to defund those projects, because one thing projects all need is money. Remember, bureaucracies and corporations respond far more to money than to any moral logic or words.

Conclusions

Bureaucracies are intrinsically immoral, seek mainly money and power, and intelligence bureaucracies are dramatically immoral because they think they are essential to their countries and governments. That hubris is only sometimes true. Bureaucracies also produce propaganda to justify both their budgets and their missions. Internal propaganda is at least as important as external, to keep employees working hard without excessive reflection. A paradox easily seen by outsiders but invisible to insiders blinded by their security rules and internal propaganda is that intelligence systems would work better if they adopted real moral codes appropriate to professionals and learned how to deal with such constraints prudently. The bureaucracies want obedience, period. Weapons of mass destruction highlight these characteristics vividly

because they are so grotesquely indiscriminate, immoral, wasteful, and some would say evil incarnate. Fear of WMDs is used to justify every other bad thing that intelligence agencies do.

All this is prelude to the key questions about nuclear weapons, and we don't want to neglect chemical and biological weapons completely. After reflection it seems the key nuclear questions are: Should anyone have them and if so when might they be morally used? How do we get from the current condition of proliferation of both weapons and fear? And how do chemical and biological conundrums compare with the nuclear dilemmas?

As George Kennan (among many others) noted, an actual, general thermonuclear war would kill billions of people and end civilization as we know it for sure. Furthermore, their destruction is so indiscriminate and unproportional to most conceivable threats that any use is likely to kill thousands of innocents along with alleged bad guys. So they are NOT just big conventional weapons. Deterring use by others has a strong surface plausibility, but continued proliferation to new and crazier entities like North Korea highlights the statistical reality that if you keep such a system forever someone is going to break the taboo and use them against others.

The paranoid will cling to them obsessively, and they will have a strong retort. Why should they not cling to deterrent nuclear weapons when all the major powers do?

There is exactly one possible moral use for nuclear weapons which is to protect the whole planet from errant asteroids or other threats from off-planet, where a detonation would not risk innocents here or the rapid escalation to general war that most Pentagon war games encounter when they practice "limited" nuclear war scenarios. Is it possible for someone to maintain a modest arsenal for planetary protection without risking the planet itself to partisan feuds?

That is a difficult challenge given the realities of geopolitics and the proven tendency of governments to become corrupt and abandon their ideal functional purposes (37). Furthermore, as Lord Acton noted most eloquently, secret power is especially prone to rapid degeneration into evil forms.[2] Nuclear weapons bureaucracies are notoriously as secret as any due

[2] Most are familiar with Lord Acton's observation that power corrupts and that absolute power corrupts absolutely. At least as relevant for secret power systems like intelligence agencies and nuclear bureaucracies is: "Everything secret degenerates, even the administration of justice; nothing is safe that does not show how it can bear discussion and

to the obvious fear that nuclear weapons designs or materials might get into "the wrong hands" which ends up being code for "anyone's hands but our Generals' who are now Emperors of the Universe."

Because of these conundrums a modest movement has arisen to urge governments to go back to the promises of the NPT and actually reduce existing nuclear weapons arsenals to ZERO excepting only a few perhaps in the hands of some new, dedicated and international entity tasked with planetary protection only. That would necessarily require actual non-proliferation to new weapons powers like North Korea, Iran or anyone else. That would necessarily require addition of Israel to the planetary WMD consensus, which would necessarily require a better resolution to the conflict with Palestinians than expulsion from the occupied territories or genocide which is the current trajectory. This is at best a long-term project, but since the alternative is civilizational suicide I suggest the relevant parties begin soon. It took decades to get here so expect decades of work ahead to walk ever so carefully out of the death ground to which we have come.

What about chemical and biological weapons, the other current WMDs, and exotic new weapons emerging like the cyber warfare crowd is working on? Here the history of arms control efforts is more encouraging. Despite many deaths and continuing chemical weapons arsenals, the long term international arms control regime appears to be working. Arsenals are declining (over 70% worldwide). By far the largest remaining are Russian and American, but both are being destroyed under careful international supervision. Dictators like Saddam Hussein who used them against neighbors at war (Iran) and even murdered ~ 5,000 of his own citizens in Halabja, Iraq on March 16, 1988 are now dead and their arsenals are really gone (38).

The Chemical Weapons Convention of 1997 created an Organization for the Prohibition of Chemical Weapons with headquarters at The Hague, Netherlands with a good track record of surveillance and eventual intervention by state parties. So their utopian goal to "eliminate an entire category of weapons of mass destruction" using unique features like mandatory "challenge inspections" of suspect sites are worth considering in

publicity." Found in a letter of January 23, 1861, published in *Lord Acton and his Circle,* Letter 74, edited by Abbot Gasquet, 1906. This suggests for this discussion that whatever institutions might be created to manage nuclear weapons for planetary protection should be far more transparent than bureaucracies ever want to be.

detail http://www.opcw.org/chemical-weapons-convention/. Once again, just because this group has a right under international law to inspect does not mean that countries like North Korea, Syria or Israel are actually going to allow inspector's access today, but the long term trends are positive. Meanwhile, the really big chemical weapons powers are actually destroying their arsenals as noted above, with rigorous observation by international parties that actually can look into any bunkers they want to. So an international consensus emerging after World War I in Europe, led to the Geneva Conventions, then the Chemical Weapons Convention, then to physical organizations staffed by real experts who are slowing accomplishing their goal of eradicating this class of WMD.

Biological weapons have killed far fewer people than either of the other categories, but are also more frightening than chemical weapons because in theory they could kill just about everyone. There is something about creating bugs that could kill everyone that seems to resonate more deeply with the moral core of scientists, soldiers and the people who support both, such that men who could order the deaths of million by nuclear weapons (or bombs and bullets) are often morally offended by the idea of biological weapons. It may help that the scientists required are "life scientists" who generally get their Ph.D.'s after long dedication to life affirming things.

One oddity bears reflection. Five Americans were killed by weaponized anthrax in 2001, that appeared a week after the famous events of September 11. Dozens of others were wounded but not killed. Who exactly did this why remains in dispute, but there is little doubt that the anthrax came from the US biological weapons labs at USAMRID (US Army Medical Research Institute of Infectious Diseases) in Fort Detrick, Maryland. Offensive weapons research at its predecessor US Army Biological Warfare Laboratories (USBWL) was officially shut down in 1969 anticipating ratification of the Biological Weapons Convention. But it is the same base, the same buildings, the same basic equipment and many of the same people were involved in both programs. Finally, "defensive research" which is allowed by the Convention requires some "offensive" biological agents to do the defensive research. So suspicion has never ended that other things may occur in such secret laboratories, as happened when the Soviets created tons of anthrax/smallpox "cocktail" weapons that should scare anyone. And that was 30 years ago. I am a geneticist; believe me,

recombinant DNA and other methods have come a long way since then. So I say, never forget that these are all bureaucracies, ergo immoral, but that they are staffed by people who have actual consciences. Appeal to them and those so that the children may survive.

Works Cited

1. Oppenheimer, J. Robert. "The Atomic bomb made the prospect of future war unendurable. It has led us up those last few steps to the mountain pass; and beyond there is a different country." This was first cited in Richard Rhode's book "The Making of the Atomic Bomb" (Simon and Schuster, 1986) which says that Oppenheimer wrote it for a commencement address he gave in 1946.

2. Einstein, Albert. Letter to US President Franklin Roosevelt dated August 2, 1939, accessible at: http://www.dannen.com/ae-fdr.html

3. Russell, Bertrand and Albert Einstein. The Russell-Einstein Manifesto, issued in London on July 9, 1955. It was actually signed by 11 extremely distinguished scientists and thinkers, and ends with this sentence: "In view of the fact that in any future world war nuclear weapons will certainly be employed, and that such weapons threaten the continued existence of mankind, we urge the governments of the world to realize, and to acknowledge publicly, that their purpose cannot be furthered by a world war, and we urge them, consequently, to find peaceful means for the settlement of all matters of dispute between them." Accessible at http://www.pugwash.org/about/manifesto.htm

4. Kahn, Herman.On Thermonuclear War, Princeton University Press 1960, and Thinking About the Unthinkable, Horizon Press, 1968.

5. Rovner, Joshua. "After Proliferation: Deterrence Theory and Emerging Nuclear Powers" Ch. 2 in Strategy in the Second Nuclear Age: Power, Ambition and the Ultimate Weapon, Washington, DC: Georgetown University Press, 2012.

6. Goldman, Jan. "Ethics Phobia and the U.S. Intelligence Community: Just Say No," in Intelligence Ethics: the definitive work of 2007*, published by the Center for the Study of Intelligence and Wisdom at Ground Zero Minnesota, St. Paul, USA, 2007.

7. Cousins, Norman. The Pathology of Power, New York, NY: W. W. Norton Co, 1987.

8. Text of this nuclear Non-Proliferation Treaty (NPT) can be found on the UN website at: http://www.un.org/en/conf/npt/2005/npttreaty.html

9. West, Nigel. Historical Dictionary of Cold War Counterintelligence. Lanham, MD: Scarecrow Press, 2007.

10. Yoo, John and Robert Delahunty wrote several memos for the Bush Administration while working in the Office of Legal Counsel that radically rethought the importance of international law (and many then current U.S. domestic laws, like prohibitions of torture andmuch of the U.S. Constitution). One dated October 23, 2001 was a memorandum for the President's Counsel Alberto Gonzales and William Haynes II, General Counsel for the Department of Defense titled "Authority for Use of Military Force to Combat Terrorist Activities Within the United States" (underline theirs) and the other, dated January 9, 2002, titled "Application of Treaties and Laws to al Qaeda and Taliban Detainees" were especially controversial because they maintained that a U.S. President at war against unconventional enemies was basically unconstrained by any treaties or laws, international or domestic. This supported the use of torture, kidnapping and deaths of many people in custody including some who in hindsight proved to be completely innocent of any crimes. These memos can be accessed at: http://www.justice.gov/opa/documents/memomilitaryforcecombatus10232001.pdf and http://upload.wikimedia.org/wikipedia/en/9/91/20020109_Yoo_Delahunty_Geneva_ Convention_memo.pdf. Most of these memos have been repudiated by subsequent Offices of Legal Counsel or even by the U.S. Supreme Court in the case of Hamdan vs. Rumsfeld in 2006, but vast damage to our international reputation and intelligence liaison relationships had already been done.

11. Gill, Peter and Michael Andregg, editors. Special Issue on "Democratizing Intelligence" for Intelligence and National Security, in press 2013.

12. Jones, Ishmael (alias). The Human Factor: Inside the CIA's Dysfunctional Intelligence Culture, New York, NY: Encounter Books, 2008, updated in 2010.

13. Anonymous (alias, a.k.a. Michael Scheuer). Imperial Hubris: Why the West is Losing the War on Terror, Dulles, VA: Brassey's Inc., 2004.

14. Mahle, Melissa Boyle. Denial and Deception: An Insider's View of the CIA from Iran-Contra to 9/11. New York, NY: Nation Books, 2004.

15. Sims, Jennifer and Burton Gerber, editors. Transforming U.S. Intelligence, Washington D.C.: Georgetown University Press, 2005.

16. Baer, Robert. Sleeping With the Devil: How Washington Sold Our Soul for Saudi Crude, New York, NY: Crown Publishers, 2003.

17. Andregg, Michael. "Do Intelligence Bureaucracies Fear Ethics, and If So, Why?" In the International Journal of Intelligence Ethics, Vol. 3, No. 2, Fall/Winter, 2012.

18. Stockwell, John. In Search of Enemies: A CIA story, New York, NY: W. W. Norton Co. 1978.

19. Marchetti, Vincent and John Marks. The CIA and the Cult of Intelligence, New York, NY: Dell Publishing, 1974.

20. Tenet, George, and Bill Harlow. At the Center of the Storm: My Years at the CIA, New York, NY: Harper Collins Books, 2007.

21. Odom, William E. Fixing Intelligence for a More Secure America, New Haven CT: Yale University Press, 1997.

22. Daugherty, William J. Executive Secrets: Covert Action and the Presidency, Lexington, KY: University Press of Kentucky, 2004.

23. Hulnick, Arthur S.Keeping us Safe: Secret Intelligence and Homeland Security, Westport CT: Praeger Publishers, 2004.

24. Crumpton, Henry A. The Art of Intelligence: Lessons Learned from a Life in the CIA's Clandestine Service, New York, NY: Penguin Press, 2012.

25. Rodriguez, Jr., Jose A. and Bill Harlow. Hard Measures: How Aggressive CIA Actions After 9/11 Saved American Lives. New York, NY: Threshold Editions, 2012.

26. Rovner, Joshua. Fixing the Facts: National Security and the Politics of Intelligence, Ithaca, NY: Cornell University Press, 2011.

27. Steele, Robert David. On Intelligence: Spies and Secrecy in an Open World, Fairfax, VA: AFCEA International Press, 2000.

28. Johnson, Loch K. National Security Intelligence, Cambridge, UK: Polity Press, 2012.

29. Blum, William. The CIA: A Forgotten History. London, UK: Zed Books, 1986.

30. Herman, Edward and Gerry O'Sullivan. The "Terrorism" Industry. New York, NY: Random House, 1989.

31. Bamford, James. Body of Secrets: Anatomy of the Ultra-Secret National Security Agency. New York, NY: Random House, 2001.

32. Priest, Dana and William M. Arkin. "Top Secret America," a four part investigative effort of the Washington Post, whose first part was published July 19, 2010 titled "A Hidden World, growing out of control, followed by parts 2 (July 20) 3 (July 21) and part 4 titled "Monitoring America" published on Dec. 20, 2010. The whole can be found at: http://projects.washingtonpost.com/top-secret-america/

33. Rich, Frank. The Greatest Story Ever SOLD: The Decline and Fall of Truth in Bush's America. London, UK: Penguin Books, 2006

34. Weiner, Tim. Legacy of Ashes: The History of the CIA. New York, NY: Doubleday, 2007.

35. Tutu, Desmond. "Nuclear Weapons Must Be Eradicated," in The Guardian, UK, March 4, 2013.

36. Wilson, Valerie Plame. "An Idea Whose Time Has Come," in the Huffington Post, March 4, 2013, http://www.huffingtonpost.com/valerie-plame-wilson/global-zero-nuclear-weapons_b_2805744.html

37. Quigley, Carroll. The Evolution of Civilizations: An Introduction to Historical Analysis, New York, NY: Macmillan, 1961.

38. Simpson, John (World Affairs Editor, BBC News). "Halabja Chemical Weapons: A chance to find the men who armed Saddam," in BBC news magazine, Dec. 2, 2012, at: http://www.bbc.co.uk/news/magazine-20553826

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Homology, Analogy and Cybernetics ideas could help the counter-terrorism effort

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Abstract
Much of the success in law enforcement can be attributed to data gathering and its analysis. While many a plot has been foiled by detective work using clues gathered from observations, some of the elements of this detective work can be formalized from concepts that are commonplace in Biology and in Darwin's theory of evolution. We establish these connections to Biology and introduce the reader to another principle that arose in the old Cybernetics movement, arguing their applicability to criminology, and clarifying the ideas so as to guide research in this fruitful area that might benefit crime prevention theory and practice.
Keywords: terorism, counter-terorrism, intelligence analysis, interdisciplinary study.

The nature of terrorism and counter-terrorism

The struggle between a terrorist attack and its counter-terrorist defenses reminds us of an example from Nature. It is the co-evolution between changes to the long bill in the oystercatcher and the flexible ligament that joins the left to the right valve in the bivalve mollusk (see Figure 1). To win its lunch, the oystercatcher must only marginally improve upon its bill overcoming a much bigger evolutionary improvement in the ligament of the mollusk.

Figure 1 – Oystercatcher opening a bivalve mollusk

The terrorist attack is like an oyster catcher's bill and its counter-terrorist defence is like the ligament of the bivalve mollusk! While a terrorist can manufacture an IED using widely available technology, it requires an enormous amount of effort, thinking, and advanced technology to design a personnel carrier capable of ensuring personnel safety against an IED explosion. Insurgents can use existing and commonplace technology: mobile phone, Internet, homemade explosives, but the defensive technology of counter-terrorism is necessarily orders of magnitude more involved and it is often leading edge technology. The defence, however, rarely stops the attack and then it often fails to sufficiently mitigate its effects. It remains extremely difficult and costly to defend against bombing campaigns, orchestrated hit and run militia activities, misinformation campaigns, and cyber attacks. At best, we can try to contain these attacks and decrease their frequency.

The value of Intelligence Analysis

Faced with this less than favourable situation, counter-terrorism activity has historically relied on the chance, induced, or coerced betrayal of the criminal organization either by its members, or by individuals in the adversary's immediate social network. Beyond tools such as the spreading of misinformation, efforts have focused on the infiltration of the criminal element by spies and undercover personnel. Through surveillance, and its reliance on the reports of informers and of the general public, counter-terrorism has been able to second guess a criminal organization to disrupt it, preventing it or delaying its operation. The value of infiltration has been to observe and to report but also to deliver advice and even to influence the conduct of the adversary from within.

Infiltration can not only be difficult, slow, and risky but sometimes impractical. For this reason, monitoring an adversary's activity over time, and the determination of patterns gathered from this activity, as input to the intelligence picture, arguably is a slow but extremely important tool of law enforcement. Such detective work holds patterns in a dual role. Patterns stimulate the construction of new theories but patterns also help to eliminate

some of the competing theories. The process of Intelligence Analysis is an active construction, an intellectual exercise which is grounded in evidence, and evidence has both a linear and a non-linear character. In a linear presentation, the frequency of a pattern and its addition to the body of evidence results in incremental progress. In a non-linear presentation, the single occurrence of a pattern may take on a defining significance.

For completion, and so as to prevent this paper from delivering an overly simplistic message, it is worth mentioning that there will always come to be instances when the availability of intelligence is judged to be detrimental. Consider the path of the Japan-US War during the Second World War. It is the considered opinion of some that the gathering and interpretation of intelligence had a detrimental effect, and that the Pacific War might have been delayed or even avoided [1]. We cannot consider in this brief paper the important psychological realities of the handling of information by the Intelligence Analysis: e.g. "warrior versus worrier" personality mix; dopamine levels; personality rivalries; and modus operandi such as "brawn versus brain", all can influence both the development and the quality of the intelligence picture [2].

The applicability of principles and laws gathered from interdisciplinary study

It is our view that the Intelligence Analysis will benefit from a number of ideas emanating from other fields. In this section, we tread upon a few of them to motivate interested readers to explore their connection to counter-terrorism.

Consider the "old cybernetics movement" that developed during the period 1950s-1970s. During the 1960s the British specialist in cybernetics W. Ross Ashby popularized a particular concept he called "the principle of requisite variety" (page 206 of [3]). Its motto is: "only variety can destroy variety". What does this mean? In layman terms, and for the benefit of our discussion, it is about attacks and responses to attacks. Every living creature has within its makeup a great number of in-built responses to a great number of possible attacks. Indeed, the power of imagination and problem solving of the human brain (and of the brains of other highly intelligent creatures) evolved to conjure up new responses to novel attacks. However, there will always be a certain type of attack for which there is no possible response: these attacks take the creature beyond the limits of its viability. For example, if the oxygen were to be taken out of the hermetic box, and nobody were to be around to respond to cries, then the creature that is trapped within the box would perish. As it has no response able to meet this attack, its viability would be compromised. This principle is apparent in many daily activities

including sport. Should two highly skilled football players meet on the pitch then the public would only see a minority of behaviours from the arsenal of their "attack and response" libraries. Indeed, we often see certain random moves with legs stepping over the ball because such "attacks" cannot by definition elicit a learned, and therefore a competent, response by the opponent.

Why do we suggest the Principle of Requisite Variety as useful to the counter-terrorism theory and practice? It is because it should assist both modelling and simulation. A further hypothetical example may illustrate this view. Imagine a nuclear disaster the size of Chernobyl with a very low background radiation in the area persisting for the following decades. It would be surprising to measure the incidence of cancer in the wild creatures that inhabit this area since the time of the accident as lower than normal! However, this counterintuitive notion is unsurprising if accounting for the Principle of Requisite Variety, but why? The principle leads us to reason that there must have been a time, millions of years ago, when a consistently and slightly higher level of radiation prevailed on this Earth. At such a time, Life might have evolved a defence mechanism against this persistent low level of radiation. This defence in the form of a chemical pathway might offer increased immunity against cancer. Such a theory is not implausible in light of the principle. In this hypothetical example, the investigator might use the principle to reason that the creature still has within it, such a fortunate response, and that the new environmental conditions might have triggered its genetic expression.

It suggests a technique. When modelling the dynamics of terrorist and counter-terrorist it is necessary to brainstorm and explore possible disruptive attacks and countermeasures of the criminal element. For some of these attacks it might be assumed that the criminal element possesses a response. Thus, sometimes *Gedankenexperiments* are sufficient instead of costly and risky validation through observation and experimentation, or instead of validation from painstaking data mining. Perhaps many attack-response pairs can be assumed to exist in this way owing to the Principle of Requisite Variety. This approach may attract criticism particularly with Reductionists but the approach is reasonable because, although it is important to collect data, it is arguably equally important to make reasonable assumptions guided by the principle.

Another principle that may be useful to Intelligence Analysis is to be found in Nature and also in Literature: "*Human nature is above all things—lazy. Every one confesses in the abstract that exertion which brings out all the powers of body and mind is the best thing for us all; but practically most people do all they can to get rid of it, and as a general rule nobody does much more than circumstances drive him to do.*" [4]. Consider the recent modelling efforts to combat drug crime in Amsterdam [5]. Although the

police constructed a social network which suggested to them how to disrupt organized crime, the disruption by police resulted in a more resilient drug network! This surprising and some may say paradoxical outcome, was probably because the original drug criminal network organization abided by the aforementioned principle of "laziness". It was organized in a less than efficient manner, and upon attack, it readjusted itself more effectively to defeat the police's interventions and attempts at its disruption [6].

Arguably, the hard sciences are not alone in establishing universal or quasi-universal principles. The Social Sciences have recently delivered a quasi-universal principle worthy of note: the "Youth Bulge Theory" [7]. It explains the conditions that lead to war, terrorism, general unrest and unstable government. For the benefit of this discussion, what can we take from the study of such a principle? Surely, it is important to understand both the causes that make a principle relevant, and to study the exceptions to the universality of a principle. Take the former for the "youth bulge": arguably its seed is the lack of education of women because if women finish some level of education then the number of children per mother drops dramatically, thus preventing the "youth bulge". What about the exceptions to universality? It becomes productive to studying rare cases that represent exceptions to the rule by means of comparisons, e.g., why did country x collapse into violent unrest and war whereas country y did not. We suggest that comparative exercises in the applicability of principles are most informative.

An important principle from Nature: Homology vs. Analogy

Further we propose that the intelligence community pay increased attention to yet another important principle from Nature. It is submitted that it is useful to learn to recognize the difference between a Homology and an Analogy in the Intelligence data.

It was Konrad Lorenz who in his 1973 Nobel Lecture [8] at the Karolinska Hospital in Stockholm first popularized the idea that the concept of homology also applies to culture and to technology. He illustrated this idea in a number of figures. We have reproduced his figure 5 as Figure 2 to illustrate this idea that depicts the evolution of train carriages. Even after the more technologically efficient concept of a central corridor was developed, many trains continued to be designed to resemble the old horse-drawn coach!

Similarly, the habits of a terrorist or criminal are inherited by his or her apprentice. As a trivial example of this, consider the design of a certain instrument of terror (IED, explosive package, misinformation campaign, computer virus, etc.). If it were possible to analyze its design, one would see within it solutions that are inherited (homology) and others which are re-discovered (analogy). To differentiate one from the other is to learn how to use homology to identify the criminal organization and its makeup.

Homologies can be easy to identify. For example, a certain design has something unnecessary and for no good reason, or it makes an arbitrary choice in the position of an item that could go anywhere, at no detriment to functionality. In such cases, such small details represent huge insights as to individual criminals and the nature of their association. The Intelligence Analyst must be trained to pay attention to such small details.

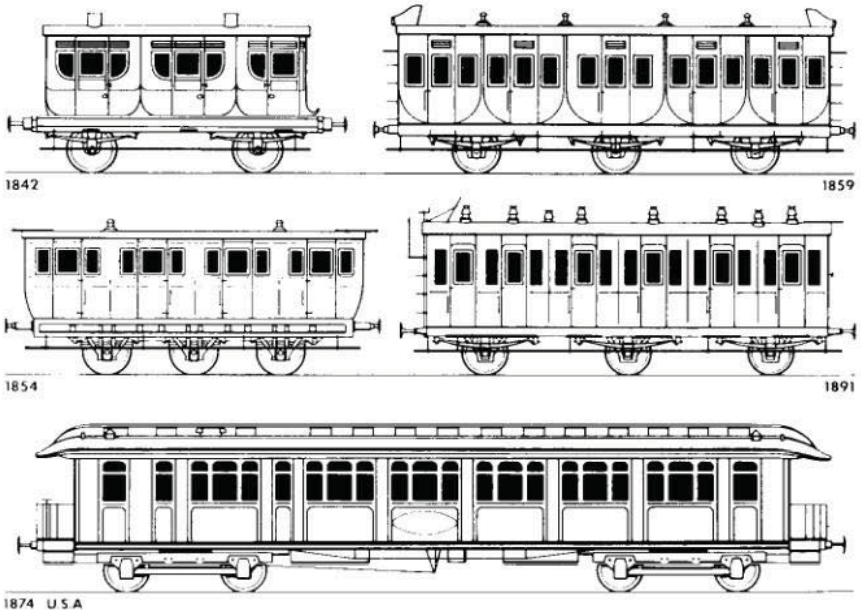

Figure 2 – Reproduced from Konrad Lorenz Nobel Lecture, 1973. It is an example of homology in technology that characters traceable to the ancestor, the horse-drawn coach should persist against the interests of technical progress in railway carriages.

Other times, however, the homologies are hard to discern. In contrast to a homology, an analogy is a principle that is independently rediscovered. For example, consider the re-discovery of flight in Nature by birds, bats, and insects. It is hard sometimes to learn to differentiate between a homology and an analogy. Here is something that would require a different type of training.

The application of homology to the natural sciences is as active today as in the past. In chemistry it is applied very successfully to the problem of protein folding and to the evolution of protein families [9]. Homology finds application in scientific fields beyond the sub-fields of Cladistics and Phylogenetics as it remains a popular concept in Astrophysics by shedding light on the seed of the structures in the Universe that we observe today.

Conclusions

Our proposal to the Intelligence Analysis community is to research how scientists have learned to differentiate an analogy from a homology in Nature. Learning this skill will enable the Intelligence Analyst to better grapple with the complexity that is inherent in detective work, with the ultimate objective of achieving timely and less ambiguous decision making.

We have also proposed familiarization with, and use of, some of the concepts that arose in the fruitful period of research between 1950^{s}-1970^{s} in the "old cybernetics" movement. The gain here is to use the principles to work with confidence to arrive at more complete models. Such concepts may help to deliver more reliable simulation models of criminal networks.

Top down models have been used to manage the under-determination that typifies detective work[i] and the Intelligence Analysis therefore has most probably adopted some of these concepts informally. However, a formal connection to Cybernetics and Biological ideas has not to our knowledge been made, nor has it been explored in the context of counter-terrorism.

Interdisciplinary study is an effective method to achieve innovation and invention. For this reason, it is submitted that Intelligence Analysis should explore all possible connections with established concepts from many other fields. Such efforts may deliver worthy contributions to its theory and practice.

References

[1] Battle Over Intelligence: the Path of the Japan-US War, NHK Documentary, 1st March, 2014, NHK World, NHK Broadcasting Corporation, Japan.

[2] Brain Games, Series 2, Episode 7. Distributor: National Geographic Channel (2011-), USA.

[3] W. Ross Ashby. An Introduction to Cybernetics. Chapman and Hall Ltd and University Paperbacks, Methusen and Co., 1964, (Reprinted 1970, SBN 412 05670 4 4.3).

[4] Harriet Beecher Stowe. In chapter 6 of "Household Papers and Stories", Boston and New York. Houghton, Mifflin and Company. The Riverside Press, Cambridge 1896. (first edition 1864).

[5] Paul A. C. Duijn, Victor Kashirin, Peter M. A. Sloot. "The Relative Ineffectiveness of Criminal Network Disruption", Nature Scientific Reports 4, Article number: 4238, 28 February 2014. doi:10.1038/srep04238

[6] Conclusion reached in discussion between Daniel Howard and Peter Sloot at the SimCity symposium at the Saint Petersburg National Research

University of Information Technologies, Mechanics and Optics (ITMO), Saint Petersburg, September 2013.

[7] Gunnar Heinsohn: Finis Germaniae? Die Zeit, KURSBUCH 162. Abgerufen am 8. Juni 2009.

[8] Konrad Lorenz, "Analogy as a Source of Knowledge", Nobel Prize Lecture, Physiology and Medicine, Karolinska Hospital, Sweden, December 12, 1973.

[9] In-Geol Choi and Sung-Hou Kim, "Evolution of protein structural classes and protein sequence families", PNAS, vol 103, no. 38, 14056-14061, Sep 19, 2006.

[10] C Baber, N A Stanton, D Howard and R J Houghton. "Predicting the structure of covert networks using genetic programming, cognitive work analysis and social network analysis" In: NATO Modelling and Simulation Group (NMSG) Annual Conference, Brussels, Belgium, 2009.

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[i] Important and practical past and present field work has succeeded by such means to thwart terrorism. Reference [10] is a recent presentation of a theoretical example that illustrates use of a top down model to manage the under-determination of theories that can arise from surveillance data: although this illustrative example may be a touch over prescriptive.

Doctrine and Intelligence

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Abstract

Development, implementation and compliance with a clear and concise intelligence and national security doctrine are a sine qua non requirement of existence, functioning and achievement of strategic and tactical objectives in any organization or nation state.

Power and performance can be achieved by public and private institutions, at both organization and state level, through strategic and doctrinal linking. Specialized intelligence and security management can operate effectively only through flexible and coherent doctrinal foundation, providing decision makers with a real advantage, based on which national security geopolitical strategies are built.

International doctrinal schools, such as those in Canada, United States of America, United Kingdom or Australia as well as NATO's, have included a series of fundamental elements in building an intelligence doctrine, which is necessary to each state that wants to embrace these principles, including at organization level.

Keywords: doctrine, intelligence, organization, strategy, transformation.

Introduction

To compare argument, and make it with the quiet tone of mutual good faith is the core of any serious discussion[1].

(Mihai Eminescu)

Accelerated development of our society is based on the rapid flow of information, which has become a powerful resource in the age of speed. Moreover, by shifting from the information age to the knowledge age, the

[1] Mihai Eminescu, Works, vol. XII, PUBLICISTICĂ, January 1, 1881 – December 31, 1881, in Timpu, VI, no. 20 of January 27,1881, including 28 reproductions of manuscripts and publications, Critical edition coordinated by Perpessicius Academy Publishing House, Bucharest, 1985, p. 46.

ratio between tangible and intangible assets has changed dramatically in favor of the intangible, reaching a score of 10 to 90. Intangible assets are built through the most important resource of the moment, knowledge, which is always based on concepts.

Within any organization operating in the knowledge era and society, everything starts from and is based on concepts. Organizations cannot progress without a clear and well-defined conceptual basis that is anchored in the conditions specific to each field and, in the case of intelligence and security organizations, in national, regional and global security framework. Today's knowledge competition is gained by those who hold supremacy in conceptual design and development of organizations. Those who design and develop new viable concepts shape the future. In this context, doctrinal construction is fundamental to any social entity's existence, survival and gaining of competitive advantage.

The intelligence doctrine is also related to the conceptual framework developed to understand and efficiently implement activities in that area (before, during and after carrying out an action) to provide military with common conduct and ideas[2]. They must represent the arsenal of knowledge enhancing joint actions, from individual to team, that are facilitated by a common language among parties, which is understood and treated in the same manner by them.

The purpose of this approach is not to launch such an initiative, but only to highlight the importance of doctrine to an organization, state some elements of interest in developing a national and organizational intelligence doctrine, and highlight issues specific to the national framework and environment.

What The Doctrine Is?

DOCTRÍNE, *doctrines, s. f. All the principles of a political, scientific, religious, etc. system – From French.* ***doctrine,*** *Latin* ***doctrina.***

(Explanatory Dictionary of the Romanian Language[3])

Any doctrine implies connecting the fundamental elements of theory, history, and practical experience in the field. In this respect, several organizations and publications have proposed definitions of the intelligence doctrine, referring to the fact that it is designed to provide broad guidance

[2] Coast Guard Publication 2-0, *Intelligence*, Washington, D.C. 20593-0001, May 2010 and Till, Geoffrey, "The Evolution of Strategy and the New World Order" in Craig Snyder (ed), *Contemporary Security and Strategy,* Palgrave Macmilan, New York (2008), p. 97.

[3] 2nd Edition, Author: Romanian Academy Iorgu Jordan Institute of Linguistics, Univers Enciclopedic Printing House, 1998, Type: Official , DEX '98.

on the use of judgment in the activities performed and to establish a common language of people working in the field.

Thus, according to the Canadian Army, doctrine is "fundamental principles by which military forces guide their actions in support of objectives". Moreover, it states that intelligence is the product of a process that involves an analysis of information to be included in the decision-making process. It is authoritative and requires judgment in application. It embraces established knowledge in the areas of planning, decision making and problem solving, sometimes being simply defined as "what is taught"[4].

Also, the Doctrine Centre of the *Australian Defense Force Warfare Centre* defines doctrine as "a description of the application of force to achieve national interests, domestically and internationally". According to the Center, the doctrine implies a philosophical military approach to the operational environment and provides a mechanism for the analysis of key operational challenges, assisting in the delivery of professional military education and training[5]. Its elaboration is part of a dynamic process based on judgment and professional experience, and its application must be tailored to a given situation, according to specific characteristics.

On the other hand, according to Geoffrey Till, the doctrine is nothing but applying strategy in a space and time context. To highlight the relationship between strategy and doctrine – considered essential to security – he makes a culinary analogy, saying that strategy is the culinary arts and doctrine the menu[6].

Last but not least, military theorists warn against turning doctrine into a dogma. For example, Sir Julian Corbett says that "nothing is more dangerous in the study of war than to allow sayings to substitute judgment". Thus, the principles of the doctrine must be always questioned, and procedures tailored to circumstances[7].

Why Do We Need A Doctrine?

"Doctrine provides a military organization with a common philosophy, a common language, a common purpose and a unity of effort."
General George H. Decker, US Army Chief of Staff (1960-1962)

[4] Canadian Military Doctrine CFJP 01, 2009.
[5] Foundations of Australian Military Doctrine, Australian Defence Doctrine Publication – D (ADDP–D), 3rd edition, Defence Publishing Service, 2012.
[6] Till, Geoffrey, "The Evolution of Strategy and the New World Order" in Craig Snyder (ed), *Contemporary Security and Strategy,* Palgrave Macmilan, New York (2008), p. 97.
[7] Till, Geoffrey, "The Evolution of Strategy and the New World Order" in Craig Snyder (ed), *Contemporary Security Strategy,* Palgrave Macmilan, New York (2008), p. 97.

The need to elaborate a national security and intelligence doctrine is obvious, given the fact that in order to be complete, an intelligence organization must have a solid theoretical and technical support, a strong strategy and, last but not least, a clear and concise doctrine[8]. All these elements are essential for a proper conduct of activity and achieving performance by an organization.

Several arguments can be raised to explain the need for a Romanian intelligence doctrine, as follows:

- First because there is none, and without strategy, doctrine, and relevant technology, an intelligence organization is not complete and therefore it does not operate effectively and does not achieve performance;
- Also, a common language that facilitates both intra-institutional and inter-institutional communication and cooperation is established through a doctrine;
- At the same time, based on a intelligence doctrine, one can efficiently and effectively fulfill the objectives and tasks;
- Last but not least, it is necessary to apply the principles of change management within the organization for them to maintain competitiveness in a knowledge society which is permanently evolving in the century of speed.

Even since the Cold War, the concept of doctrine has been used predominantly in the military, but the intelligence activity, especially that at the national level, did not have a specific doctrine for all actors operating in the field. The military doctrine can be defined as the set of prescriptive principles guiding the use of armed forces of a state in pursuing its interests in times of peace and war[9].

Military organizations have traditionally provided information to their forces in three ways: orders, intelligence, and doctrine. Orders are used to define a specific task. Intelligence provides information about the environment in which the task will be accomplished. Doctrine establishes the "rules of the game" or standard operating procedures. Unlike orders and intelligence, doctrine is not provided in real time, but it serves to establishing the culture and mentality of the individuals involved. The information was, until recently, inseparable from commanders, command structures, and command systems[10].

As for Romania, in 2004, the Romanian Intelligence Service had the initiative to develop such a document, which was approved by the Supreme

[8] Barger, D. G., *Toward a Revolution in Intelligence Affairs*, RAND Corporation, National Security Research Division, 2005.
[9] Russel, F. Wieigly, *The American Way of War: A History of United States Military Strategy and Policy*, New York, Macmillan, 1973, p. 512.
[10] Alberts, D. S. *The Unintended Consequences of Information Age Technologies*. NDU Press Book, 1996.

Council of National Defense as "The National Security Information Doctrine". Experts in the field mention the following about the respective document:

"If an academic approach to the problem of the intelligence community is wanted, then, all the same people have to accept that its necessity results from the Intelligence Doctrine. This doctrine exists and perhaps the above-mentioned people have coordinated and participated in drafting and endorsing it in the Supreme Council of National Defense, during 2001-2004. It can be accessed on the Presidency website, its full name being the National Doctrine of Security Intelligence.

Indeed, the doctrine seeks an academic approach, except for the fact that, as it is conceived, it has no power and clarity to generate the concrete framework to organize and develop a new intelligence activity needed by our country in the process of training and consolidating the democracy and the rule of law".

"The intelligence doctrine and the intelligence community remain simple academic digressions, excuses for Bucharest-style political tensions or they are claimed as a need for reform towards democracy?"

Mihaiu Margarit, Brigadier General (r), former Chief of the Military Intelligence Directorate, Project manager at EURISC Foundation - European Institute for Risk, Security and Communication.

The above-quoted military intelligence specialist indicates that the move is unsubstantiated, being historically inadequate to the current conditions and needs of Romania and its intelligence services. With a view to arguing this idea, he mentions the need to change the doctrine, regarded as the only way to develop the organizational culture, particularly at the level of the organizational management. The organizational culture can be changed by replacing it with another form of behavior, while in order to implement the formulated strategy, each member of an intelligence organization must know how to change the manner of performing tasks.

Alberts Davis considers that the process of drafting the doctrine tends to be slow and difficult due to the large number of people and organizations involved. Even so, it is further necessary to ensure consistency of appropriate behavior throughout the organization[11]. Besides that, there is also the reluctance of members to changes in the organization, once a new doctrine and measures that precede it are implemented.

For an intelligence organization to maintain its flexible and adaptive nature – fundamental attributes of any social group or form of organization in the contemporary era – it needs a doctrinal construction. Once it is formulated, implemented and assumed by all group members, individuals on lower levels gain flexibility in creation and adaptation, as long as their actions

[11] Alberts, David S. *The Unintended Consequences of Information Age Technologies*, NDU Press Book, 1996.

are subsumed to the general framework formulated by the management, which allows them to operate more quickly and more efficient.

In this context, the interdependent relationship among *strategy*, *doctrine* and *intelligence* emerges, the reference of American strategist John Boyd's vision on the adaptability and responsiveness of individuals within the organization – "*He who best manages changes, survives*" – to the scale of dynamic capabilities enounced by Sun Tzu – known as "*the speed beats strength, speed beats surprise, surprise beats strategy*", being worth mentioning [12].

The absence of a doctrine in the intelligence field or the existence of an unclear doctrine, with poorly defined terms and concepts, without logical and conceptual construction, hinders the development of reforms and transformations in relevant organizations. Here it is worth noting two important elements: on the one hand, the difference between reform and transformation, often misunderstood either by politicians or by some intelligence leaders of the last quarter century, and, on the other hand, the way of elaborating the legislation, regulations and instructions in the intelligence field. This is a step of the trinomial which links theory, education and practice. Therefore, the elaboration of laws, rules and instructions requires first the clear establishment of theory, strategy and doctrine of the respective field. This explains why the amendments to the legal framework or changes in the management of intelligence services have not always had the desired effect, namely that in the absence of a doctrine, each intelligence structure provided its own interpretation, as an integrated vision lacked.

In this regard, experts point out that, in a chaotic world, leaders need to rethink the organizations they lead through underlying concepts, principles and values, not by developing rules[13]. And this is possible in Romania. Let's go through them one by one.

According to Webster's dictionary, to reform means "to return to a good state". The majority of individuals perceive the reform as an effort to improve or eliminate shortcomings of a situation, process, product, etc. A second definition attributed to reform is "the action to improve social or economic conditions without a radical or revolutionary change". Based on this definition, we can conclude that the implementation of a reform

[12] Osinga, Frans P. B. *Science, Strategy and War: The Strategic Theory of John Boyd*. London: Routledge, 2007.
[13] Pinchot, G. and E. Pinchot. *The End of Bureaucracy & the Rise of the Intelligent Organization*. San Francisco: Berrett-Koehler Publishers, 1993.

requires the maintenance of the existing form, aiming just to rearrange components in order to eliminate the deficiencies.

However, on the other hand, to transform means to change the form, not just to rearrange it. In nature, transformation involves not only a change in appearance, but also in the character and life of an organism (for example, the transformation of a caterpillar to a butterfly). Unlike reforms, transformations can involve changes with negative impact: at the individual level, we can notice changes in the way of thinking that, once produced, completely change the configuration mode of the cognitive process, eliminating thus any way back.

Also, when we talk about transformation, we must realize its meaning. Thus, according to Ackoff (2004), reforms and transformations are not the same. Reforms aim at changing the means by which goals are achieved, and transformations involve changes in pre-established objectives. These changes occur in relation to the evolution of intelligence: activities of services/ intelligence communities' members come in response to internal and external factors, by replacing the objectives, and to changes that occur outside the intelligence field. Sometimes the respective changes and trends are not addressed in a timely manner by practitioners and academics, or they are addressed only partially. The major difference between reform and transformation is similar to investment in tangible versus intangible assets.

Organizations that manage to make especially long-term investments in intangible assets will be able to get a competitive advantage in the field/market/sector where it acts. To that end, the intelligence field and discipline have come of age in the last two decades, and a market of economic, competitive, technological, business, academic, etc. intelligence begins to take shape within it requiring a clear-cut and dynamic strategy, where only those organizational, state or private entities that design and implement concepts and models of action with which they can outperform competitors achieve great results.

In this context, an organization or a state without doctrinal construction or with a poor intelligence doctrine cannot operate and effectively operate, so therefore we cannot speak of a viable transformation.

What Should an Intelligence Doctrine Contain?

A first step in detecting the elements underlying the building of an intelligence doctrine is a benchmarking analysis on profile documents in various countries of the world. To this end, we can examine the constituent elements of doctrine in the United Kingdom, France, Canada, Australia and the United States of America.

In any activity, achieving performance and obtaining success consist primarily in the correct understanding of the nature of that activity and its principles. The same reasoning applies to the intelligence field, as well. Experts stress the importance of the aims pursued, and clarify the relationships established with the decision-making factor and the operational area[14]. Considering our situation, the first step would be to take into account Romania's NATO membership acquired in 2004. To that end, the challenge of our mission should be diminished since we already have a fundamental North-Atlantic doctrine. Unfortunately, however, the real situation differs from reality, the topic on which we will resume later.

By analogy, the Canadian intelligence doctrine – Joint Intelligence Doctrine – represents "a guide for all those involved in the intelligence process". This material addresses topics such as: the nature of intelligence, the process of intelligence, intelligence practice, and intelligence support for planning, the operational intelligence and guidelines for joint intelligence[15]. To be useful and efficient, the doctrine should specify the authorized command relationships and authority that military commanders can use, provide guidance for the exercise of that military authority, provide fundamental principles and guidance for command and control, prescribe guidance for organizing and developing joint forces, and describe policy for selected joint activities[16].

The US Army document – "Intelligence Field Manual No. 2-0" – represents the fundamental material for the military intelligence doctrine. It describes the bases of intelligence operations, intelligence warfighting function, the intelligence process, the roles and functions of military intelligence in the context of military operations, the intelligence in unitary action, intelligence concepts in preparing strategic and intelligence-related disciplines.

According to Brunel Centre for Intelligence and Security Studies/ BCIIS, a doctrine should also provide servicemen the following elements meant to guide them and help them in their work: a guide to best practice in the field, a learning platform, a document that sets out the responsibilities in carrying out their duties, a database that can be extracted from the rules and regulations and an "aide-mémoire" for officers during operations[17].

Another document on intelligence doctrine of national importance is Joint Doctrine Publication 2-00 from Great Britain. It comprises the intelligence theory, practice and procedures, described in six major themes:

[14] Marine Corps Doctrinal Publication 2, 1997.
[15] Joint Intelligence Doctrine, Canadian Forces, Publication B-GJ-005-200FP-000, 2 October 2002.
[16] Doctrine for the Armed Forces of the United States, Joint Publication 1, 2013.
[17] BCISS, 'BCISS Comments on JWP 2-00 Re-Write Arising from DCDC Intelligence Seminar', December 3, 2009.

understanding and influence centrality, the importance of intelligence exploitation, inter-institutional cooperation and joint cooperation procedures, command – staff relationship, intelligence in the contemporary cooperation environment.

In the French version[18], an intelligence doctrine must approach the following areas: the type of intelligence and its customers (including the subject and the definition of intelligence, decision-making levels, the types of intelligence used by decision-makers), intelligence origins with "information bank" from which intelligence is extracted and intelligence production (including the fundamental principles of intelligence and intelligence cycle).

If we try to summarize the contents of the American, British, French and Canadian doctrinal schools' documents, we could highlight a few fundamental doctrinal benchmarks needed in the construction of an intelligence doctrine. They consist in understanding environmental intelligence, the nature of intelligence, bases/theory of intelligence, which includes the creation and development of an effective intelligence, an intelligence cycle, and the role and functions of intelligence.

In the case of drafting a Romanian conceptual doctrinal base, a first step could also be the observance of the above-mentioned algorithm. It is not necessary to develop it now, but some clarifications are important at this stage.

A first indication refers to the pattern we approach when conceiving and drafting an intelligence doctrine. In this case, the pattern is adjusted to architecture of the team conceiving and drafting the doctrine. This architecture must respect logical chaining of the research-education-occupation trinomial (or learning-theory-practice), so that the team conceiving and drafting the doctrine is heterogeneous, including also experts of the three elements of the trinomial and the conceiving/drafting stages are formalized in an information flow on the departments related to this formula. Therefore, the academics and research experts have to support a first draft doctrine, for a previous configuration of its content with the help of operational experts. We do not intend to elaborate now on the cooperation way and the instruments used in the actual activity.

A second indication is related to identifying and understanding the intelligence environment. Within this context, before conceiving and drafting the doctrine, it is necessary to analyze the intelligence environment, an environment included in a certain context having several components. An intelligence environment could consist of: strategic context – made up of international security environment and the national intelligence environment

[18] La stratégie mondiale en matière d'information et de renseignement, 2005.

and the specific context – represented by the intelligence environment specific to the organizational entity. The projection of the elements is necessary for each of the two components.

Things seem to be very clear in the case of our country as far as the intelligence framework is concerned: there is no intelligence community in Romania. An explanation to that end is the understanding of the phase we have reached in training intelligence officers. Human capital development has not been considered important in Romania, a proof to that end being the education system. Intelligence services and community have to reconsider their position towards scientific national security-related research by projecting and setting up a national systemic intelligence. Why do we say that? Because from many reasons our efforts to build an intelligence community in Romania have failed. One of them is that the policy makers have not understood the role of intelligence in the knowledge society, and by that we mean the two executive branches – the Government and the Presidency – which both wanted to control the community or to keep it as far as possible out of the political reach. However, that's not why we have failed. The main reason of our failure is that we did not understand the processes behind creating such an organizational entity: national intelligence community. In order to succeed in setting up the community, we have to start not with legislation, legal framework and rules but with the concepts projection, definition, and elaboration, starting with intelligence in case we decide to maintain this word into Romanian language. Another reason of our failure is that we have to understand the tangible and intangible assets because we do not clearly comprehend the importance of intangible assets within an organization in Romania.

And a third reason is related to the nature of intelligence and intelligence discipline theory. Thus, intelligence represents the activity of intelligence and security services and agencies. From theoretical point of view, we talk about intelligence as a social sciences domain or what we can consider to be *academic intelligence.* It includes academics, experts in the field who became trainers and professionals who subsequently achieved academic status by developing their competencies in research or education.

Amid this context, one has to have in mind the nature of current intelligence field and discipline which is quite different of one century or ten years ago. Human society rapid development and the transformation of information era into knowledge society with steps towards intelligence era (as Dedijer and other specialists have anticipated even from 2002) produce significant changes in intelligence activity.

This leads to reconsider the specific taxonomy of the discipline by projecting new concepts related to current reconfiguration of the social organizational models. One example to that end would be the creation of

academic intelligence, a concept initiated by us few years ago to connect the academic, educational, and operational "tribes" and to fuel the development of intelligence knowledge

If we were to follow the evolution of the intelligence concept, which started with the actions and operations developed under the shadow of secrecy and undercover actions, but also to analyze its biological (Fedanzo, 1993), organizational (Lippmann, 1922, Wilensky 1967), and business side specific to the last decades, we would notice its extended translation to all people in the society and its transformation into a systemic entity that produce knowledge through models of learning and continuous adaptation to dynamic market demands, this time under the rule of "openness".

Intelligence is a knowledge process. If initially intelligence developed as an essential part of military capabilities, nowadays it has become an important part of every organizational capability, taking into account all its components from political, to social and economic ones.

While the elaboration of an organizational doctrine might be considered a simple process if we understand the nature of intelligence, but this is not the case, the extension of the doctrine to state institutions, by taking into account the two private and public elements, transcend the knowledge operational limits.

After clarifying the nature of intelligence we can strengthen the theory of this discipline. But we will discuss this complex topic later.

Conclusions

We cannot talk about a scientific paper on information on Romanian historical and ideological space due to the fact that the last century topics in the Romanian specialty literature are only information history-related and case studies. The absence of a specific Romanian intelligence theory and doctrine led to the development of contemporary intelligence systems that triggered obvious and significant differences. To conclude, this state of mind can trigger the emergence of an *agnotologic intelligence*[19] rather than an *epistemological intelligence* that is useful to most of the people. The main effects are to be felt at the level of operational experts who could pay attention to research and education only from operational perspective. To that regard, a potential development of a Romanian intelligence doctrine

[19] Agnotology describes and studies culturally induced ignorance or doubt, particularly the publication of inaccurate or misleading scientific data. The term was introduced in „*Agnotology: The making and unmaking of ignorance*" (2008) by professor specializing in the history of science Robert N. Proctor.

could be done by using the collaborative principles and methods for joint teams of experts from both operational and academic spectrum.

Bibliography

Volumes

1. Alberts, D. S. 1996. *The Unintended Consequences of Information Age Technologies*. NDU Press Book.

2. Barger, D. G. 2005. *Toward a Revolution in Intelligence Affairs*, RAND Corporation, National Security Research Division, available at http://www.rand.org/pubs/technical_reports/2005/RAND_TR242.pdf, accessed on March 31, 2014.

3. Baud, J. 1997. *Encyclopedie du Renseignement et des Services Secrets*, Lauvazelle Publishing House.

4. Eminescu, M. Opere, vol. XII, PUBLICISTICĂ, January 1, 1881 – December 31, 1881, in Timpul, VI, no. 20, January 27, 1881, Bucharest: Academiei Publishing House.

5. Fedanzo, A. 1993. *A Genetic View of National Intelligence. Second International Symposium: National Security & National Competitiveness: Open Source Solutions Proceedings*, Volume I, available at http://www.oss.net/dynamaster/file_archive/040320/445214476d2a9a34cda719d17ded8fa7/OSS1993-01-04.pdf

6. Kent, S. 1955. *The Need for an Intelligence Literature*, în Studies in intelligence, No. 1, September 1955.

7. Kent, S.1964. *Words of Estimative Probability*, Studies in Intelligence, Fall 1964.

8. Lippmann, W. 1922. *Public Opinion*. New York: Harcourt Brace Print.

9. Osinga, Frans P. B.2007. *Science, Strategy and War: The Strategic Theory of John Boyd*. London: Routledge.

10. Pinchot, G., Pinchot, E. 1993. *The End of Bureaucracy & the Rise of the Intelligent Organization.* San Francisco: Berrett-Koehler Publishers.

11. Ransom, H. 1970. *Intelligence Establishment*, Harvard University Press, *apud* Alain Dewerpe. 1998. *Spionul – antropologia secretului de stat contemporan*, Bucharest: Nemira Publishing House.

12. Russel, F. Wieigly. 1973. *The American Way of War: A History of United States Military Strategy and Policy*, New York: Macmillan

13. Wilensky, H. L. 1967. *Organizational intelligence; knowledge and policy in government and industry*. New York: Basic Books.

Articles

14. Dedijer, Stevan. 2002. *Development & Intelligence 2003-2053, National Security and The Future* 3(3-4).

15. Sebe, Marius. 2011. *Why Intelligence*, Bucharest University Anales, Political Sciences Series, Year XIII (2011), no. 2.

16. Till, Geoffrey. 2008. *The Evolution of Strategy and the New World Order*, in Craig Snyder (ed), *Contemporary Security and Strategy,* New York: Palgrave Macmilan.

Electronic Publications

17. BCISS, "BCISS Comments on JWP 2-00 Re-Write Arising from DCDC Intelligence Seminar", December 3 2009, available at http://people.brunel.ac.uk/~isstppd/BCISS%20Comments%20on%20Joint%20Intelligence%20Doctrine%20December%202009.pdf, accessed on November 20, 2013

18. Doctrine for the Armed Forces of the United States, Joint Publication 1, 2013, available at http://www.dtic.mil/doctrine/new_pubs/jp1.pdf, accessed on March 29, 2014.

19. Canadian Military Doctrine CFJP 01, 2009, available athttp://publications.gc.ca/collections/collection_2010/forces/D2-252-2009-eng.pdf, accessed on March 29, 201.

20. Coast Guard Publication 2-0, *Intelligence*, Washington, D. C. 20593-0001, May 2010, available at http://www.uscg.mil/doctrine/CGPub/CG_Pub_2_0.pdf, accessed on March 29, 2014.

21. Foundations of Australian Military Doctrine, Australian Defence Doctrine Publication–D (ADDP–D), Third Edition, Defence Publishing Service, 2012, available at http://www.defence.gov.au/adfwc/Documents/DoctrineLibrary/ADDP/ADDP-D-FoundationsofAustralianMilitaryDoctrine.pdf, accessed on March 29, 2014.

22. Joint Intelligence Doctrine, Canadian Forces, Publication B-GJ-005-200FP-000, 2 October 2002, pp. 1-3.

23. Joint Doctrine Publication 2-00 (JDP 2-00), Understanding and Intelligence support to joint operations, Third Edition, August 2011, available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/33704/20110830JDP2003rdEDweb.pdf, accessed on March 29, 2014.

24. La stratégie mondiale en matière d'information et de renseignement, 2005, available at http://tinyurl.com/klaynsl, accessed on March 29, 2014.

25. Marine Corps Doctrinal Publication 2, Department of the Navy, Headquarters United States Marine Corps, Washington, D. C. 20380-1775, June 7, 1997.

26. https://www.cia.gov/library/center-for-the-study-of-intelligence/csi-publications/books-and-monographs/sherman-kent-and-the-board-of-national-estimates-collected-essays/6words.html

27. http://www.csis.gc.ca/bts/ntllgnc-eng.asp/ Canadian Security Intelligence Service.

28. http://www.cisc.gc.ca/aciis/aciis_e.html/ Criminal Intelligence Service Canada, Automated Criminal Intelligence Information System.

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Functional Cathegories in Intelligence Support[*]

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Abstract

Intelligence support is a communication process and the communication models, communication functions and other psychological concepts are relevant for understanding the role of both intelligence operators and decision-makers, as well as specific functions of intelligence support. Differences in these functions are supported by the amount of actionable intelligence and by the level of Clausewitzian friction involved in the security/operational situation.

Consequently, three functions of intelligence support are suggested: construction of intelligence superiority, warning, and integration into action.

Keywords: intelligence support, communication process, actionable intelligence, clausewitzian friction, intelligence superiority, warning, decision-making, risk management.

Intelligence support as communication process

As well known, the meaning of intelligence is to support with intelligence products decisions to be taken at various levels in operational planning or in the wider realm of national security. Therefore, essentially, a structure specialized in a certain domain transfers an informational content to a structure which uses this content to decide and trigger certain actions. Described this way, intelligence support is, obviously, a communication process.

According to the Explicative Dictionary of Romanian Language (DEX), the verb «to communicate», derived through French from the Latin

[*] This paper uses sections of Mircea Mocanu, *A Novel View on the Intelligence Cycle in Network Centric Warfare Conditions*, PhD thesis, National Defence University "CarolI", on July 6, 2013, pp. 109-135.

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verb «*communicare*», defines the action of "letting known", "informing", "conveying news", "saying".[1] The DEX definition identifies only the informational substance as object of communication. However, other definitions provide a larger scope for the contents being transferred to the recipient: "communication is a process by which persons share information, ideas, and feelings"[2] or "communication is a process of transmitting a sense from somebody to somebody else"[3]. We see that not only information is transferred during a communication, but also *feelings*, *ideas*, and *sense*, which holds water for intelligence support as well.

For all these types of transferred content, the intelligence structure has the competence to store/process/generate professional contents, thus being the *epistemic authority* of the intelligence domain. The recipient of transferred contents – the beneficiary of intelligence support – would then utilize these contents to make decisions regarding concrete actions, process which reflects the quality of *deontic authority* for the beneficiary of inteligence products.

The above mentioned positioning is relevant for researches on the functional rapport between these two parts of the communication process because it defines the limits between the entire intelligence structure – the epistemic domain – and the decisionmaker, who belongs to the deontic domain, responsible for the commands on any level of the sistem (in this case, the military system or, writ large, the national security system).

Looking at communication as *transactional process* between two parts, one can notice the signification of a basic *transactional analysis* principle, which states that the *role* of each party determines the character of communication by the adaptation of communication to serve the relation defined by the *roles of the parties*[4]. Again, this underlines clearly the limit where intelligence structure ought to stop before jeopardising its epistemic role. This is «the red line» where the intelligence product, albeit a mere verbal briefing, risks to cross into the deontic domain, where it suggests solutions, recommends a certain decision or another, asuming, this way, a deontic role.

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[1] *** *Explicative Dictionary of Romanian Language* – DEX, Romanian Academy, Bucharest, 1984, p. 179.
[2] Sandra Hybels, Richard Weaver II, *Communicating Effectively*, Random House, New York, 1986, p. 6.
[3] Dorina Sălăvăstru, *Education Psychology*, Collegium – Psychology Series, Polirom Publishers, Iaşi, 2004, p. 174.
[4] Sandra Hybels, Richard Weaver II, *op. cit.*, p. 14.

The relevance of this functional rapport resides in the fact that transfer is not conducted in view of storing the communication content or with other inert aims, yet with the deliberate objective to make decisions which lead to actions, even very important actions, considering the social impact they might entail. Actually, "communication has always an end, an objective, an intentionallity, which can be explicit or implicit"[5]. This is an important point in analysing communication. The destination of communication – the decision in view of an action – is well known to both parties, and the emitter cannot ignore the finality of the transfer and formulates the content in a manner coherent with the intended utilization. In other words, an important aspect of the transferred content is the substance which concretely supports the objective of the recipient's activity – the action. Thus, communication needs to include «actionable substance». In intelligence language, this requirement reflects in the necessity to transmit «actionable intelligence».

Models of the communication process

Communication is a bidirectional process and researching the transfer from the intelligence structure to the beneficiary of intelligence products – one of the transmission senses – requires the examination of both the intelligence structure role, and the decisionmaker's role. In this respect, it can be noticed that the definition in DEX reflects the vision of one of the *two classes of models of communication processes* – the *mathematic model*, informational and linear, respectively the *psycho-sociologic model*, of *interactionist* nature[6]. More exactly, the reference exclusively to information as object of the transfer corresponds, mainly, to the classic theory of information, fathered by Claude Shannon. This theory describes communication in a mathematic/cybernetic manner, only from the points of view of the mechanism, the volume/quantity of transmitted information, and of the fidelity of the transmission process, but with no reference to the content/the quality of the transmitted content.

[5] Jean-Claude Abric, *Psychology of Communication: Theories and Methods*, Polirom Publishers, Iaşi, 2002, pp. 15-32.
[6] Dorina Sălăvăstru, *op. cit.*, p. 176.

John Fiske[7] called this model the «process school», which "sees communication as transmission of messages... and is interested especially in issues like efficiency and accuracy of the message transmission". This technical feature explains the wide use of this model in information technology (IT), using the well-known graphic[8] displayed in Figure 1. In the same time, this model sees communication as "a process by which [the emitter] acts upon the behaviour or state of mind of another individual"[9].

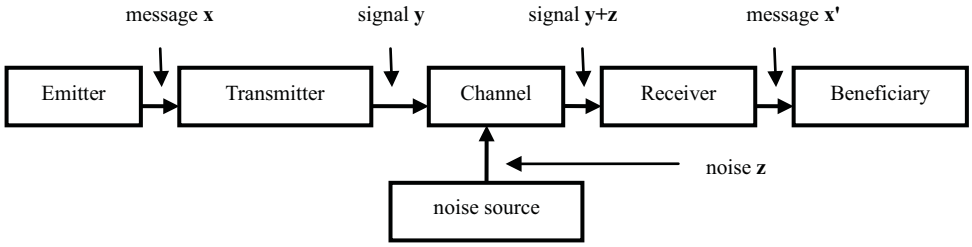

Fig.1. Shannon and Weaver model for the communication process

The other model of communication, the *psycho-sociologic model*, conceptualized by the Palo Alto School[10], adds to the mathematic model the social context, the interaction between the Emitter and the Beneficiary, which implies action and reaction, thus being a circular, not a linear model[11]. In the case of intelligence product dissemination, this model implies a dynamic interaction between the intelligence structure and the beneficiary, a complex transaction and not a simple cybernetic transfer. This interaction

[7] John Fiske – American phylosopher and historian, professor at Harvard University in the second half of the XIX-th Century.
[8] www.veghes.ro.
[9] This paragraph includes quotations from John Fiske, *Introduction to Communication Studies,* Methuen, New York, 1982, *apud* Vasile Tran, Irina Stănciugelu, *Communication Theory*, Comunicare.ro Publishing House, National School of Political and Administrative Studies (SNSPA), Department of Communiction and Public Relations „David Ogilvy", Bucharest, 2003, p. 39.
[10] Group of researchers of various specialties (sociologs, linguists, psychiatrists, antropologists) united around Gregory Bateson. Palo Alto School includes Donald Jackson, Paul Watzlawick, Janet Beavin, Edward Hall, Ray Birdwhistell, Erving Goffman, Margaret Mead, Virginia Satir, Jay Haley, John Weakland, Richard Fish and others.
[11] Dorina Sălăvăstru, *op. cit.,* pp. 176-177.

implies awareness regarding the fact that the objective of intelligence support is altering the behaviour of the beneficiary, in a logic assumed by both parties and based on a common interest. Actually, as Shannon and Weaver stated, "the word communication has a wider sense, it includes all processes by which a spirit can affect another spirit"[12].

Consequently, intelligence production is influenced by specific factors called «determinants» which reflect analyst conditions such as his experience, his perception of reality, conceptions and convictions, as well as analytic errors and bias, his intentions and orientation towards an interest common with the beneficiary, but also his own creativity and professional qualities. In the same way, the decision-maker consuming the intelligence product is influenced by personal conditions such as his perceptions, expectations, conceptions and beliefs, his personality, experience, leader qualities, bias and creativity. In addition, decision-maker's intentions range wider than those common with the intelligence structure, which is the common interest expressed in commander's intent or the political project pursued by the decision-makers.

The absorbtion of the elements introduced by the social context, for the case of the models generated in interactionist approach, as mentioned above, as well as the aproximation of the real communication channel by an ideal channel, with zero noise, allow reaching beyond Shannon's mathematic model. There, the conditionings operational both at communicator end and recipient end can be outlined according to the graphic presented in Figure 2, for the communication process adapted to reflect the intelligence support.

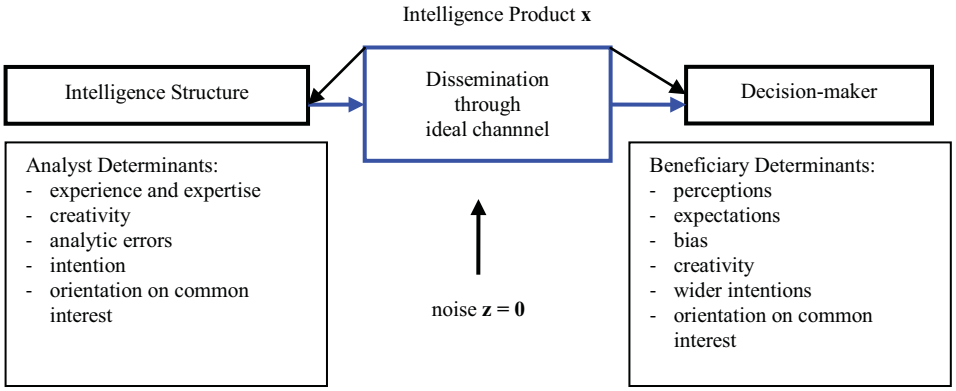

Fig. 2. Conditionings operational in intelligence support as communication process

[12] Vasile Tran, Irina Stănciugelu, *op. cit.*, p. 12.

Of course, this model works both ways, the reverse way reflecting the reaction from the decision-maker, who becomes communicator towards the intelligence structure.

John Fiske termed this model the «semiotic school», for which "performing communication means producing also an exchange of senses (significations)". For this model, "the object of interest is the study of the way the messages interact with people to produce *meanings* (or *significations*)"[13].

The roles of participants in intelligence support

However, the encyclopaedic dictionary defines the action of communicating as "the fundamental mode of psycho-social interaction of persons through an articulate language or through other codes, in view of transmitting an information, of obtaining stability or individual or group behaviour modifications"[14]. In another definition, communication is "a process by which an emitter transmits information to the recipient... with the aim to produce certain effects upon the recipient"[15], and "*the act of communication ends with practical implications upon the recipient*, the final stage of the information transfer"[16]. This underlines the natural fact that the recipient is an integral part of the functional model representing processes operating with information, intelligence included.

The same idea is expressed as representing a *power relation*: "an individual has power upon another if he can fulfil an action able to produce a change in the second individual"[17]. The factors which generate this influencing ability are agent properties called by the two authors «*power resources*». At the other end, the values of the target individual – in the case of intelligence support, the beneficiary of intelligence products – are termed

[13] This paragraph includes quotations from John Fiske, *Introduction to Communication Studies, apud* Vasile Tran, Irina Stănciugelu, *op. cit., Communication Theory*, p. 39.
[14] Vasile Tran, Irina Stănciugelu, *op. cit.*, p. 11.
[15] J.J. Cuilenburg, O. Scholten, G.W. Noomen, *Communication Science*, *apud* Vasile Tran, Irina Stănciugelu, *op. cit*., p. 16.
[16] Vasile Tran, Irina Stănciugelu, *op. cit.,* p. 15.
[17] Dorwin ***Cartwright***, Alvin ***Zander,*** **Group Dynamics,** *apud* Vasile Tran, Irina Stănciugelu, *op. cit.*, p. 110.

«*motivational bases of power*». Psychologists Cartwright and Zender argue that "an act of influence establishes a relation between the resources of an agent and the *motivational basis* of the influenced individual"[18]. Thus, intelligence support establishes a relation between the intelligence structure resources and the decision-maker motivational basis, which is reflected in the management conception and risk management policy.

These power relations are broken down into five power cathegories: *rewarding, coercive*, *legitimate*, *referential*, and *expert* power[19]. Among these, psychologists French and Raven define the expert power as "the influence based on superior kowledge attributed to the communicator and having affect upon the cognitive structure of the recipient"[20]. Applying these concepts to intelligence support seen as a communication process, one can notice exactly the situation of intelligence structure's epistemic authority vis-à-vis the beneficiary of intelligence products. So, the production of an effect of cognitive nature is based on the acceptance of the intelligence structure expert status by the beneficiary of intelligence support in the domain where communication is performed, i. e. the intelligence domain.

The role difference in decision-maker and intelligence structure also marks the positioning of the two parties according to one of the two communication axioms, that "any communication process is either symmetric or complementary, depending on its basing on either egality or difference"[21]. In the case of intelligence support, the process is complementary, because the beneficiary holds the upper hand, according to Palo Alto School scholar Paul Watzlawick's explanation: "In a complementary relation, two different positions are possible. One of the partners holds a superior position..., primary or one-up, while the other holds the corresponding position, described as inferior, secondary or one-down"[22]. This role difference has clear consequences on intelligence

[18] *Ibidem*.
[19] John P. French, Jr., Bertram H. Raven, *The Bases of Social Power*, 1960, *apud* Vasile Tran, Irina Stănciugelu, *op. cit.*, p. 111.
[20] *Idem*, p. 112.
[21] Dorina Sălăvăstru, *op. cit.*, p. 180, with details about these axioms in pp. 178-181.
[22] Paul Watzlawick, Janet Beavin, Donald Jackson, *Pragmatics of Human Communication. A Study of Interactional Patterns, Pathologies and Paradoxes*, *apud* Dorina Sălăvăstru, *op. cit.*, p. 180.

support, because "the complementary interaction is based on maximizing the difference, which can lead to communication blockage"[23]. In intelligence, these problems can occur when the content of intelligence products is altered to please the beneficiary's vision, when the intelligence structure abuses by treading into the deontic domain – the realm of political or military decisions – or, the extreme case, when the decision is manipulated on purpose.

So, the study of intelligence support as communication process highlights the action and role of intelligence after the transfer is completed, the fact that the beneficiary of intelligence products belongs to the communication process, and the usefulness of intelligence products when the actionable intelligence is an integral component of decision and action.

Communication functions and the actionable content of intelligence products

The study of intelligence support as communication process is relevant from the point of view of functionality, because either the success or failure of intelligence can have important consequences in defence or security. This is why the best investigation path seems to lead to the communcation functions. For the particular case of linguistic communication, six functions have been identified[24], which can be extrapolated for the communication process, in general:

- The «*conative*» function, which expresses "the capability of communication to produce effects upon the recipient", for example orders, requests, manipulation, advice, marketing messages, propaganda, recommendations. This function of linguistic communication bears no relevance for intelligence support, because the intelligence structures have to stay within the limits of its epistemic role, and to abstain from formulating recommendations. Obviously, references to any other example mentioned above are useless and alien to intelligence domain;

[23] Dorina Sălăvăstru, *op. cit.*, p. 180.

[24] Roman Osipovici Jakobson, *Linguistic and poetry*, Moscow, 1896, *apud* Christian Baylon, Xavier Mignot, *Communication*, „Alexandru Ioan Cuza" University Publishing House, Iaşi, 2000, pp. 83-85, and the same for the quotations in the following paragraphs referring to the communication functions.

- The «*referential*» function is centred on the transferred content and "represents the communication capability to refer to a certain *state of facts*", expressing the "orientation of the message towards reality", and speaking to the recipient's intellect, to the quantitative, mathematic side of his perception;

- The «*poetic*» function is centred on the transferred content and "expresses the capability of communication to cross beyond the sense of words and determine certain *emotional states*". This function does not limits to literature, and includes messages not stemming directly from the objective substance transmitted, but views elements of qualitative nature, non-quantifiable, which speak to the «*affective side*» of the recipient's decisional mechanism;

- The «*emotional*» or «*expressive*» function "highlights the emotional states of the emitter", being centred on it and has no relevance for intelligence domain, where the analyst's momentary emotional state have no importance;

- The «*meta-linguistic*» function refers to communications regarding the very transmitted message, its structure, and the code used for the transfer to recipient;

- Finally, the «*fatic*» function is a function of technical nature and refers to the capacity of the transmission channel to assure the transfer of the contents.

Among the above mentioned functions, the poetic and the referential functions are worth researching for the intelligence domain, because they are centred not on the emitter, the transfer mechanics or the transmission channel, but on the content transmitted to the recipient and on the effect produced by the transfer of this content to the decision-maker. So, there is great interest in analyzing the substance included in the intelligence structure's product which has relevance for understanding the effect generated by intelligence support, substance which continues its existence and produces effects after the dissemination of intelligence products.

Logically, the intelligence support aims at bringing the beneficiary to a favourable situation for making a wise decision, this way being "an instrumental or *alloplastic* communication"[25] (i. e. the modification

[25] Dorina Sălăvăstru, *op. cit.*, p. 189.

of somebody else). Thus, the intelligence support reflects the communication objective to "modify the state of the beneficiary, albeit his cognitive state, affective state, his predisposition to action or the action itself"[26].

The role assumed by intelligence support speaks to the process of *social influencing* as "action exerted by a social entity (person or group), oriented towards the modification of another entity's actions or manifestations". This influence is based on one of the power relations mentioned above, specifically on the *expert power,* associated to the intelligence structure epistemic authority. The French sociologist Raymond Boudon argues that the mechanism of this influence as power relation is *persuadation,* which needs two conditions to work:

- the communicator should hold an acceptable degree of *competence* and *information*, which speaks to the epistemic authority of the intelligence structure;

- the influencing relation should be based on the *consensus* of the parties participating in the communication process regarding the shared values, the objective and the envisaged effects. In intelligence support, this cohesion reflects the attitude of serving the national interest, or the commander's intent, for the case of military operations, in the same risk management/operational conception.

To make sure that the epistemic role of intelligence structure is preserved, it is clear that social influencing, as a process associated to intelligence support, must be confined to persuadation about certain realities and probable evolution perspectives of the events, not at all about the concrete option the decision-maker should choose as beneficiary of intelligence products.

This rationale speaks to the «*actionable*» *aspect* of the content within the message transmitted to decision-makers by the intelligence structures. The content may refer either to simple data necessary for decisionmaking (for example numeric values, like calendaristic data or geographical coordinates), or other actionable elements able to trigger motivations or affective states which generate decisions. Contemporary psychologists specialized in communication propose[27] another typology

[26] *Idem*, p. 188.
[27] Dorina Sălăvăstru, *op. cit.*, pp. 189-190.

of communication functions, ignoring the engineering elements of the communiction machine. This typology identifies the cognitive, affective, actional, and socialisation functions, all relevant for intelligence support.

These functions defined for the communication process generate effects which have correspondence in intelligence as follows:

- the *cognitive function*, corresponding to the Jakobson's referential function reflects the general providing of information in intelligence, which contributes to knowledge development for achieving informational superiority;

- the *affective function* triggers *motivations* related to the common interest served by the two parties for securing the opportune response to the security challenges, type of response necessary especially under pressure, i. e. under time constraint;

- the *actional function* concretely supports decisions by the sheer usefulness of the actionable intelligence and transfers the contents directly into action;

- the *social function* builds a community between the intelligence structure and the beneficiaries of intelligence products, by serving the common interest (commander's intent), and achieving an effective professional relation.

In order to complete the conceptual framework of intelligence support as communication process, it is useful to detail the form of communication the intelligence support can take along three criteria[28]: the manner or technique of transmitting the message, the way the actors participate in the communication process, and the way communication process is performed.

From the point of view of the way intelligence products are transmitted, intelligence support can be either a *direct* communication (for example, in the case of oral briefing), or an *indirect* communication, in the case of using secondary techniques: written reports, electronic communications.

Considering the participation mode, intelligence support is either *interpersonal* or *group* communication, the latter being conducted between persons belonging to the same organisation - the case of intelligence reports disseminated inside a military structure or inside the national security system.

[28] Vasile Tran, Irina Stănciugelu, *op. cit.,* p. 18.

Finally, by the way communication is conducted, intelligence support can be an *ascendent/upwards* communication (when the beneficiary is a decision-maker up-stream the chain-of-command), a *horizontal* communication (towards coworkers of the same level, in cooperation exchanges), or a *descendent/downwards* communication (from a higher echelon intelligence structure towards execution level organisations).

Given that intelligence support is sometimes destined for planning staff (in military operations) or politicians (for example, in the case of intelligence products provided to defence commissions of the parliament), the social/group communication, destined to groups of recipients, becomes the relevant type of communication. This is typically the situation of intelligence briefings, where psychologists identify six roles of communication[29], having the following connotations for intelligence domain:

- *It contributes to achieving group task,* role expressed in intelligence by the very purpose of its products – support for operational/ political decision.

- *It supports group cohesion* by clarifying the context and harmonizing opinions, in the process of building the *common operational picture* (COP) – in the military – or a *shared awareness* of risks and threats – in the security domain;

- *Raises the group to a higher value* as recipient of communication, which means, in intelligence, an improvement in the cognitive domain, by absorbing the commander's intent and forming a common vision of the operational/international security situation;

- *Acts as groups' unity factor*, a role associated to those mentioned above for intelligence domain;

- *Solves group's internal problems* – role also associated to the previous;

- "*Helps the group become a reference for the individual*"[30], which, in intelligence, supports the relevance of mission, danger, risks, threats, and opportunities for all echelons of military or political decision.

In the logic of all examined functions, the communication element instrumental for establishing the effect of intelligence support on decision

[29] Dorina Sălăvăstru, *op. cit.*, p. 189.
[30] Adrian Neculau, *Leaders in Group Dynamics*, Scientific and Encyclopaedic Publishing House, Bucharest, 1977, pp. 82-83.

and action is the «actionable» content, which weighs differently in intelligence products and has various effects upon the beneficiaries, according to the response time it requires.

Consequently, the «actionable» substance included in intelligence products has a paramount importance in shaping the intelligence support functions from the point of view of communication usefulness and of the practical destination of intelligence products. The functions of intelligence support are discriminated by the energy of the «actionable» substance applied in decision and in the action based on this decision. The resulting functional classes also reflect the impact of the time pressure and the emergency of response measures necessary to be taken by the system in risk management activities. Both time pressure and response emergency surge when the common interest served jointly by the intelligence structure and the beneficiary of intelligence products is jeopardised.

Classes of intelligence support according to the «actionable» substance and Clausewitzian friction

Even since 1950, immediately after the foundation of the modern concept of intelligence by Sherman Kent, the American geographer Norton S. Ginsburg stated that "intelligence derives its *raison d'être* from conflict, whether in time of peace or war. Its goal at all times is not the maintenance [*sic*] of peace nor the provocation of war, but preparedness for the latter"[31]. When analysing intelligence through the perspective of confrontation, the research of intelligence support requires the consideration of Clausweitzian concepts of war friction, danger, superiority, and surprise.

In the logic of preparation for conflict, Mark Lowenthal argues[32] that the *raison d'être* of intelligence services requires: *avoiding surprise* (strategic and tactical), support with expertise projected on long term, support of political decision-makers, and the protection of secret

[31] Harold M. Greenberg, *Intelligence in the past, Intelligence in the Media*, *apud* Loch Johnson (coord), *Strategic Intelligence*, Praeger Security International, 2007, Westport CT, 2007, p. 173.
[32] Mark Lowenthal, *Intelligence from Secrets to Policy,* Congressional Quarterly Press, Washington DC, 2003, pp. 2-5.

information, requirements (including financial) and methods. This approach is somewhat eclectic, including all aspects of intelligence activity, in the absence of a thorough analysis of intelligence support and ignoring the tricky issue of the intelligence cycle. Lowenthal's approach offers an unquestionable practical value inside the intelligence structures, but with little relevance for the research of intelligence life after the phase of dissemination. However, the logic of these pages requires the consideration of the first component mentioned above, i.e. avoiding surprise.

From the point of view of performing intelligence support as communication process, the functionallity of intelligence activity needs to be analysed like an architecture organised in the cognitive domain, meaning knowledge, understanding, information superiority over a potential enemy. This perspective has been underlined by the French psychologist Rodolphe Ghiglione, in the concepts specific to social representation and cognitive psychology theory regarding communication: "the individual who communicates is not just a mirror reflecting the reality; he is, especially, the permanent builder of social reality. We have here the proposition of a new paradigm: communication as process of *social «co-construction».* From this perspective, among the functions accomplished by communication one can identify the *construction of the reference univers"*[33].

In intelligence, this construction of the reference univers translates by the evaluation of the security environment, more exactly by activities such as: security phenomena monitoring; risk, threat and opportunity identification; production of assessments which approximate reality as close as possible; performing warning about dangers against interests of military or security nature; and producing prognoses about future evolutions within the military/security environment.

In all these activities, the intelligence structures exert *social influence* operating upon beneficiary's cognitive domain by alloplastic communication in order to determine the generation of effects of deontic nature, i. e. to trigger decision-making and issuing of dispositions/military orders. For the intelligence structure, the instrument of this action is the

[33] L. Iacob, *Research on Communication Today*, apud Adrian Neculau, *Social Psychology. Contemporary Aspects*, Polirom Publishers, Iaşi, 1996, p. 185.

intelligence product: periodic bulletins, pinpointed campaign intelligence reports (SPOTINTREP), briefings, annual national intelligence estimates, intelligence assessments, long-term prognoses and others.

Besides circumstances connected to dissemination context (peace, crisis or war), the place of intelligence product consumption (head of state cabinet, battlefield), beneficiary (brigade commander in operation or European Union programme planner) or the physical support of the intelligence dissemination, the intelligence product contains more or less «actionable» information, according to the intelligence product purpose: "the final product... needs to be disseminated to beneficiaries... to realise planning support, influence decisions and the way actions are executed, and prevent realising surprise"[34] by the adversary. Considering the «actionable» contents of intelligence products, the intelligence activity shells various functionalities which can be associated to the functions mentioned above for the communication process.

However, it is hard to imagine an intelligence product having zero content of «actionable» intelligence, since the intelligence structures always aim to deliver useful products in order to assure relevant support to decision-making finalised by concrete actions. Even at the highest level, "wisdom means the turning knowledge into useful action. So, knowledge becomes an abstract good"[35]. Therefore, the destination of «actionable» intelligence is important, that is the action to be triggered by the beneficiary, considered in connection with the danger/opportunity it answers to.

Thus, for routine planning activities (for example, in the case of multi-annual governmental programmes), the «actionable» intelligence is not associated to emergency actions, wrought under time pressure, which alter the working pace specific to normality, but are transferred calmly into actions of planning adjustment.

Considering intelligence which detects the perspective of dramatic modifications of the security/operational situation, even in the absence of an armed confruntation, a pre-conflict Clausewitzian friction appears. In this

[34] Sergiu T. Medar, *Intelligence for commanders*, Military Technical Publishing Centre, Bucharest, 2007, p. 25.
[35] George Cristian Maior, *Editorial* in *Intelligence,* magazine of the National Intelligence Academy "Mihai Viteazul", nr. 21, Bucharest, March-May 2012.

case, intelligence products *warn* the beneficiary, meaning that they stimulate the generation of a reaction with an affective component, based on the common understanding of the fact that a common interest is jeopardised or favourized by an event which can occur in a relatively short time, i.e. under time constraint.

Finnaly, in the situation of a response to an acute political crisis or during a military operation, the Clausewitzian friction is intense and the intelligence products contribute directly to the editing of decisions and get directly integrated into the very actions, even up to being automatically transferred into electronic commands which trigger the action of combat equipment (in the case of electronic warfare).

Functionalities in intelligence product utilisation

If the main goal of intelligence activity is avoiding/preparing surprise by warning about dangers or opportunities, other functions of intelligence support refer to utilisations emplying less or more «actionable» substance than in the case of warning, or another rapport to the time factor, and reflect lower or higher levels of Clausewitzian friction.

The communication function easiest to translate to intelligence domain is the *referential function,* which reflects the transfer of information to the beneficiary by referring to realities about which the decision-maker should be aware for a good performance according to his duties. The referential function is simple to term as information function, by which intelligence support contributes to achieving general *informational superiority* by *building intelligence superiority,* in conditions of low Clausewitzian friction. Writ large, in the wider scope of risk management, the *construction of informational superiority* is described as "the state of relative advantage in the informational domain achieved by assuring the right information to the right beneficiary at the right time and in the right form, and, in the same time, forbidding the adversary to do the same thing"[36]. Bearing this in mind, intelligence support fulfils its meaning even when a content of «actionable» substance is destined not for an urgent

[36] ***, *NATO Information Management Policy (NIMP)*, C-M(2007)0118, Allied Command Transformation, Norfolk VA, US, 13.12.2007.

response to a danger jeopardising the main interests of the system, thus with no time constraint, but for a systematic elaboration of a future response, i. e. for a perspective planning or understanding a security situation with no pressing risks or threats.

Of course, informational superiority serves to achieve military superiority. Carl von Clausewitz reserves a subchapter of his masterpiece "On War" to military superiority, but he only deals with numeric superiority, which he considers "the most important factor in battle". This is quite normal in the conditions of the military art of that era, considering that the armies were "much more similar to one another regarding weaponry, organisation, and technical knowledge of all kinds"[37] and there was no force projection, remote strike, mass destruction capabilities, computer networks or air capabilites whatsoever.

David Omand[38] considers that the finalisation of intelligence support includes three areas, all pertaining to the *construction of intelligence superiority*, here identified as one of the intelligence support functions. D. Omand proposes[39] the conceptual organisation of the intelligence support utilisation in three domains, according to the temporal perspective of analysis. These areas/«uses» are *explanation* – oriented towards the past, *building situation awareness* – linked to the present, respectively *prediction* – projected towards future events. Obviously, between these cathegories of intelligence product utilisation there is no clear separation, each of the three «uses» having relevant values reflecting the other two.

The *function of warning,* already established in intelligence, implies, of course, transfer of information, but also presents a component of the *poetic*/*affective* function, as a communication function, because it crosses beyond the mechanical transfer of information to generate or feed motivations

[37] Carl von Clausewitz, *On War*, Military Publishing House, Bucharest, 1982, p. 182.
[38] Sir David Omand, GCB, was Intelligence and Security Coordinator in the British Cabinet Office from 2002 to 2005. He has also been a member of the Joint Intelligence Committee, Permanent Secretary of the Home Office and the Cabinet Office, Director of the Governmental Communications Headquarters of (GHGC) and Deputy Under Secretary of State for Defence Policy. He is, in March 2014, visiting Professor in the War Studies Department of King's College London and honorary Fellow of Corpus Christi College, University of Cambridge.
[39] David Omand, *Securing the State*, Hurst and Co., London, 2010, pp. 24-26.

beyond the mathematic calculus, namely in the afective domain. This way, intelligence support determines employment of ambition, courage, cunning, and preservation instinct. Facing a higher level of Clausewitzian friction, this implication has the nature to trigger decisions in view of concrete and relatively quick actions meant to lead to avoid danger, secure the most appropiate response to the detected danger or to the exploitation of opportunities with the goal to accomplish the mission. All these reactions face the constraint of a limited implementation time.

For warning in the military domain, without naming intelligence, Clausewitz identifies the role of intelligence support in adapting the effort of the system's own military organism, as the crisis escalates or the fighting actions unfold: "the relative superiority, meaning the shrewd manoeuvre of superior forces in decisive points, is based on the corect judgement of these points and on the adequate orientation"[40].

The third communication function selected for the research of intelligence support as communication process is the *actional function*, which highlights the most practical destination of the transferred information, namely their *integration into action*, *with a short and precise temporal perspective*. In this case, the corresponding function in intelligence can be named exactly «*the actional function*», which would define, for the intelligence products, a dominant content of actionable intelligence which is transferred immediately into decisions and actions. In a Clausewitzian approach, this function defines the situation of already engaged confruntation, characterized by a maximum friction, when the forces engaged in conflict seek to diminish the friction perceived by own forces, and to transfer the conflict friction to the adversary, following the battlerhythm. This «intense» domain of intelligence support can be exemplified by the situation of fighting actions or by the case of acute political-diplomatic crises. The extreme situation is that of intelligence operations, where the action is performed intensely inside the very intelligence system, and the intelligence products are an integral part of the very core of the concrete action.

[40] Carl von Clausewitz, *op. cit.*, p. 184.

Conclusions

The arguments presented in these pages lead to the conclusion that the construction of intelligence superiority, the function of warning, and the actional function can be considered functional cathegories of intelligence support, discriminated by the pressure/urgency of «actionable» intelligence utilization, by the rapport between the intelligence operator and the effect of his activity, as well as by the intensity of Clausewitzian friction associated to the confruntation perspective.

The consideration of these functional cathegories does not require modifications in intelligence production or the introduction of new types of intelligence products. However, it allows a better understanding of the intelligence support effect upon the decision-makers and also opens the avenue of researching the way to optimize the integration and utilization of intelligence activity in risk management and decision-making at all levels.

Bibliography

1. *** *Explicative Dictionary of Romanian Language* – DEX, [Romanian] Academy Publishing House, Bucharest, 1984.

2. *** *NATO Information Management Policy (NIMP)*, C-M (2007)0118, Allied Command Transformation, Norfolk VA, US, 13.12.2007.

3. Jean-Claude ABRIC, *Psychology of Communication: Theories and Methods*, Polirom Publishers, Iaşi, 2002.

4. Christian BAYLON, Xavier MIGNOT, *Communication*, University „Alexandru Ioan Cuza" Publishing House, Iaşi, 2000.

5. Carl von CLAUSEWITZ, *On War*, Military Publishing House, Bucharest, 1982.

6. Sandra HYBELS, Richard WEAVER II, *Communicating Effectively*, Random House, New York, 1986.

7. Loch JOHNSON (coord), *Strategic Intelligence*, Praeger Security International, Westport CT, 2007.

8. Mark LOWENTHAL, *Intelligence from Secrets to Policy,* Congressional Quarterly Press, Washington, 2003.

9. Sergiu T. MEDAR, *Intelligence for Commanders*, Defence Technical Publishing Centre, Bucharest, 2007.

10. George Cristian MAIOR, *Editorial,* in *Intelligence,* magazine of the National Intelligence Academy "Mihai Viteazul", nr. 21, Bucharest, March-May 2012.

11. Mircea MOCANU, *A Novel Vision on Intelligence Cycle in Network Centric Warfare Conditions*, PhD thesis defended at National Defence University "Carol I", Bucharest, July 6, 2013.

12. Adrian NECULAU, *Leaders in Group Dynamics*, Scientific and Encyclopaedic Publishing House, Bucharest, 1977.

13. Adrian NECULAU, *Social Psychology. Contemporary Aspects*, Polirom Publishers, Iaşi, 1996.

14. David OMAND, *Securing the State*, Hurst and Co., London, 2010.

15. Vasile TRAN, Irina STĂNCIUGELU, *Communication Theory*, comunicare.ro Publishing House, National School for Political and Administrative Studies (SNSPA), Department for Communication and Public Relations „David Ogilvy", Bucharest, 2003.

16. Dorina SĂLĂVĂSTRU, *Education Psychology*, Collegium. Psychology series, Polirom Publishers, Iaşi, 2004.

17. www.veghes.ro.

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Intelligence analysis and possible intelligence failures. Qualitative research accomplished on a particular case: news on the Russian military presence in the Mediterranean.

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Abstract

Every day we are besieged with news, questions and comments on various themes. Nowadays the quantity of data is not a problem any longer. Therefore assessing priorities in the process of collecting data needs a certain "vision" upon the information which must be searched for and collected. Identifying other factors, which might influence analysis, beyond those which are accounted by the individual, is one step forward in containing errors. Although intelligence failures abound, we lack positive intelligence theories. This qualitative research tries to exhibit how intelligence analysis based on perceptions can be affected and by which factors.

Keywords: intelligence analysis, intelligence, intelligence failures, qualitative research, focus group.

■ Sources of intelligence analysis failures

▪ Richard Heuer[1] highlights both the value and the danger of mental patterns. The author states that analysts build their own version of "reality", based on information filtered through perceptions. This input is mediated by mental complex processes and might determine what information is retained, how information is organized and what meanings are assigned to that kind of information.

[1] HEUER Jr., Richard J., Psychology of Intelligence Analysis, Center for Study of Intelligence, Central Intelligence Agency, 1999, pp. 10-21 și pp. 116-120.

What people perceive, how readily they perceive something and how they process information upon reception are factors strongly depending on previous experiences, education, cultural values, role requirements and organizational rules as well as the peculiarity of the information/data received.

This act can be compared with the perception/cognition of the world through a lens, which directs, amasses and, therefore, can distort the image. Lenses are known under different names – mental patterns, bias/predilections or analytical assumptions[2].

▪ The volume *Intelligence analyst's guide, Compendium for junior analysts*[3] inventories psychological limits as causes for intelligence failures, namely:

1. Memory vulnerabilities (the inability to save a great deal of information, the tendency to classify information on categories).
2. Cognitive/intellective errors (the image in a mirror, mental inertia, inability to recognize and identify misinformation).
3. Default reasoning (new information blurred by previous ones or by analyst's experiences and beliefs).
4. Inappropriate parities (false similarities between events/ new postures and older ones).
5. Overly positive thinking ("Pollyanna complex") or overly negative thinking ("Cassandra complex").

Pursuant to psychological errors, I briefly need to mention few causes, as they have been identify in *Ars Analytica*[4]: metal pattern, memory, lack of empathy, cognitive laziness, illusion of causality, confirmation bias, category classification prejudice, theory of commitment and reconfirmation.

▪ Other authors highlight failures derived from methodologies: either underdeveloped (which leave analysis rather in an experimental area)[5]

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[2] *Ibid*.

[3] MICU, Manuela; VÂLCEANU Corin, *Factori care determină/influenţează procesul analitic. Limitele psihologice şi erori de analiză*, în Ionel Niţu (coord.), *Ghidul analistului de intelligence, Compendiu pentru.*

[4] MAIOR, George Cristian; NIŢU, Ionel, Ars Analytica, Editura RAO, Bucureşti, 2013, pp. 295-297.

[5] JOHNSTON, Rob, *Analytic Culture in the US Intelligence Community*, Center for the Study of Intelligence, Washington, 2005.

or overly developed (which may restrict their analysis in terms of limiting the necessary perception/intuition and flair)[6].

For example, Rob Johnston argues that "intelligence analysis errors are factual errors, resulting from insufficient information or lack thereof. Intelligence failures are due to inaccurate, outdated, inappropriate assumptions or forecasts"[7].

▪ The fact is, that based solely on analysts' individual/cognitive skills, intelligence analysis may fail.

"Analysts' prejudices have repeatedly limited answers to the information needs of consumers. Thus, from the Japanese attack on Pearl Harbor to the erroneous estimation by the CIA (2002) on the existence of weapons of mass destruction in Irak (during the Saddam Hussein regime), the lack of sufficient critical thinking over potential crises, has produced mistakes in the assessment process of information."[8]

▪ Some authors emphasize that errors are not so often intelligence generated, but rather coming from the level of on decision making (beneficiaries, politicians).

Richard Betts believes that military disasters befall some states no matter how informed their leaders are, because their capabilities are deficient.[9]

Same author points out that errors may occur due to different perspectives held on same facts, especially when it comes to estimates/predictions.

"There is an axiom that a pessimist sees a glass of water as half empty and an optimist sees it as half full. In this sense, the estimative system is a glass half full. Mistakes can happen in any activity. Particular failures are accorded disproportionate significance if they are considered

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[6] HEUER Jr., Richards J.; PHERSON, Randolph, *Structured Analytic Techniques for Intelligence Analysis*, CQPress, Washington D. C., 2011.

[7] JOHNSTON, Rob, *Analytic Culture in the US Intelligence Community*, Center for the Study of Intelligence, Washington, 2005, p. 67.

[8] NIȚU, Ionel, *Analiza de intelligence. O abordare din perspectiva teoriilor schimbării*, Editura RAO, București, 2012, p. 101.

[9] BETTS, Richard K., *Analysis, War and Decision. Why intelligence failures are inevitabile*, în GILL, Peter; MARRIN, Stephen; PHYTIAN, Mark, *Intelligence theory: Key Questions and Debates*, Taylor and Francis, Studies in intelligence series, 2008, p. 106.

isolation rather than in terms of the general ratio of failures to successes; the record of success is less striking because observers tend not to notice disasters that do not happen."[10]

▪ Finally, other authors emphasize the inability to prevent all risks, due to the "black swan" phenomenon.[11]

With this background in mind I have tried to accomplish a qualitative social research starting from Richards Heuer's "lens theory".[12]

■ **Research**

In early October 2013, I have conducted a study based on a qualitative research (focus-group), accomplished together with a company specialized in social researches (X), under the coordination of an intelligence analyst and author of several books in the analysis field (Y).

▪ **Context:** News regarding Russian Federation intention to deploy troops and naval military capabilities in the Mediterranean.

▪ **Method used for research**: Conducting focus-groups

▪ **Purpose:** To what extend and by which factors can intelligence analysis be influenced?

▪ **Hypothesis of the research**

The objective we started our research with was to find out to what extent may intelligence analysis (based on perceptions) be influenced and by which factors (beyond those related to the individual)?

We have chosen several students and MA graduates from two universities (humanities major) and we grouped them by six, in three different teams (team 1, 2 and 3).

[10] *Ibid*, p.107

[11] TALEB, Nicolas, *Lebăda neagră. Impactul foarte puţin probabilului,* Editura Curtea Veche, Bucureşti, 2008.

[12] HEUER Jr., Richard J., Psychology of Intelligence Analysis, Center for Study of Intelligence, Central Intelligence Agency, 1999.

▪ **Intelligence Input**

We selected a story about the deployment of Russian military forces (permanent) in the Mediterranean basin (Hotnews, "Russia wants to relocate a permanent fleet in the Mediterranean", signed by R.M. on 03/11/2013)[13].

After a brief search, I identified dozens of articles on the same subject, all published in the same period of time (e. g. Karadeniz Press, 03/17/2013, Vitalie Goncearov, "Russian Navy began preparation for deployment of permanent naval forces in the Mediterranean")[14]

Almost none of the various pieces of news was presented in simple, neuter tones. At a first glance, various authors used same process of building up impressions on comments, in order to support a particular hypothesis.

Most of the columns hinted at Moscow's intention to restore its area of influence and to Russia's need to have access to the Mediterranean, as a space of confluence and transit between Asia and the West, between North Africa and Europe. The texts drew similarities between the current state of the art and the Soviet Navy's deployment of navy forces in the Mediterranean during the Cold War. Other comments suggested that the Western strategic advantage created by the missile shield was thus neutralized, they hinted at the Russian intention to control trade routes between the Black Sea, the Red Sea and the Mediterranean etc. Other comments connected events to the tense developments in Cyprus, the Arab Spring, and the conflict in Syria etc.

Obviously, such pieces of news were the result of subjective interpretations of information. When I started to make my own search on this issue regarding Russian military presence in the Mediterranean, I found out that such news was published regularly for more than a year. So, in fact, the news on Hotnews portal or Karadeniz Press were not at all new, they were resuming (by using, indeed, a recent statement) an older idea. None of the articles (neither written press, as gandul.info[15], nor audio-visual media,

[13] http://www.hotnews.ro/stiri-international-14396958-rusia-vrea-reamplaseze-flota-permanenta-marea-mediterana.htm, seen on October 2, 2013.

[14] http://karadeniz-press.ro/kara/rusia-in-permanentizeaza-misiunea-navala-in-marea-mediterana/, seen on October 2, 2013.

[15] http://www.gandul.info/international/marina-rusa-a-inceput-sa-lucreze-la-crearea-unei-forte-de-interventie-in-mediterana-10661873, seen on October 2, 2013.

as realitatea.net[16] and articles on news agencies such as mediafax.ro[17] or specialized sites like ziare.com[18]) published during this period, did not report that, in fact, such news appear episodically for over a year. Almost every time, such news was sparked by a declaration of an "official" from Moscow.

Therefore, I wondered whether this too was a case in which one could very well apply Heuer's theory on the analysts' bias to interpret/filter reality through their own "lens", marked not only by their own experiences (influenced by culture/civilization they belong to), but also by their own limitations, prejudices, stereotypes etc.

I also wondered to what extent the context (political, economic, military, etc.) can influence our analytical thinking, causing failures.

With all of the above in mind, I also wondered if – based on Stanley Milgram's experiments (regarding obedience)[19] – a person with authority/professional legitimacy can change perceptions and opinions of a group of analysts.

In March 2013, the conflict in Syria was not very noted, but disputes over oil reserves in the vicinity of Cyprus (Turkey had already deployed military forces in the area) were highly publicized, and the international context in Middle East seemed to get more and more complicated (Iran's nuclear agenda, Turkish-Israeli tensions, etc.).

Therefore, multiple meanings can be conceded to the Russian Officer's statement.

▪ Intelligence analysis' variables

Thence, I set myself to evaluate how analysis may be influenced, presetting the subject of analysis, namely the news and context described (when, occasionally both the moderator and one of the group members took

[16] http://www.realitatea.net/marina-rusa-lucreaza-la-crearea-unei-forte-de-interventie-in-mediterana_1132571.html, seen on October 2, 2013.

[17] http://www.mediafax.ro/externe/marina-rusa-a-inceput-sa-lucreze-la-crearea-unei-forte-de-interventie -in-mediterana-10661814, seen on October 2, 2013.

[18] http://www.ziare.com/international/siria/rusia-trimite-vase-de-razboi-si-trupe-in-siria-desfasurare-de -forte-ca-pe-vremea-urss-1178374, seen on October 2, 2013.

[19] http://www.infopsihologia.ro/2011/12/fenomenul-obedientei/, seen on October 2, 2013.

a clear position on subject review). The favorable context was the opportunity to appoint focus groups together with specialists whose charisma helped changing the context of the news processed and analyzed.

Consequently, we had two variables (modified news and context) – and I wanted to see if, lest, we will acquire 2 or 3 different conclusions/ analysis/evaluations, although the news accrued from a single (real) statement, and the context as well as the mindset are issues that should not excessively effect analysis. Proficient analysts know they have to expel noise when recovering the sound.

However, we have done just that: we embedded noise.

Doubtlessly, our subjects were not intelligence analysts, but students and MA graduates who are, however, familiar with scientific research methodology, have critical attitude and they can (though they are convinced they can) perceive the reality and are convinced they cannot be manipulated.

Therefore, the original story (the one on Hotnews.ro) has been deliberately modified, generating an exaggerative news (item no. 1, Annex 1), some attributes (especially adjectives and complements) have been, where appropriate, strengthened or added to the story.

In the initial news we have removed most of the attributes, obtaining a neuter style of presentation of news, in which adjectives and complements which might indicate a certain subjectivism were avoided as well as the author's conclusions, generating item no.2 (Annex 2).

After an analysis of all the reports published last year, I have made a selection of the stories on the same subject (item no. 3 – representing a selection of about 17 pages in Annex 3).

▪ **Course of research**

1. The team of 6 subjects was asked to interpret Item no.1, after a brief presentation of the context conducted by a moderator.

The mediator brought forward the context in specific terms of Cold War, depicting Russia as USSR successor trying to rebuild its sphere of influence. An increased attention has been attached to the MD (missile defense), suggesting to the subjects that, in fact, notice of deployment of Russian troops in the Mediterranean is meant to limit the strategic advantage created by the placement of missile shield elements in Romania.

The subjects were asked to discuss and then to extract answers to the following questions[20]:

a) What is Russian Federation's real purpose?

b) Is it just a statement, or Russia would send troops to the Mediterranean?

c) Does this statement have an effect upon Romania?

After only half an hour, subjects concluded, without major differences of opinion (except on answers hierarchy according to the degree of probability).

Answers:

a) Russia wants to recover losses anguished after Cold War; Russia wants to rebuild spheres of influence held by USSR; Russia wants to sabotage/cancel West strategic approaches (Western countries and the U. S.), namely those obtained by NATO expansion.

b) It is a statement that will be implemented.

c) This will cancel the strategic advantage obtained by Romania for hosting U. S. military troops, respectively, by hosting elements of the future missile shield.

Therefore, team no. 1 was prone to take contextual elements foreshadowed by moderator, being clearly influenced by far-fetched news (item no.1).

2. Next team was given the news no. 2 (Item no. 2), without giving prefabricated elements as context, but the events of recent months (Arab Spring, missile shield, tensions in Cyprus and Middle East).

With no context elements preset, team no. 2 – exposed to an extremely clear, but drily news – was extremely difficult to answer the three questions.

The correlation degree of responses was reduced, one of the subjects – who proved certain knowledge of the subject – to some extent, influenced the perception of the whole group.

However, most subjects exhibited their findings, undertaking their own hypothesis and assumptions – mainly pre-set – so that similar responses to team no. 1 have been answered but no implications of alleged missile defense have been evidenced.

[20] Same questions in same order have been asked to all 3 teams.

Team no. 2 could not assess the degree of implementation of the statement, so that equal scores have been recorded as follows: is just a statement (threat), respectively, it will be implemented in the future.

Being exposed to an intentionally altered context (as the team no.1 was as well), team no. 2 could not establish a connection between the Russian Officer's deliverance and the decision to host MD elements in Romania.

Answers were as follows:

a) Russian Federation wishes to rebuild the USSR's area of influence; Russian Officer's statement shows Moscow's concern towards NATO approach to its borders; Russia wants to control trade routes crossing the Mediterranean; Russian military troops' intention is to intervene in favor of its allies (Iran, Syria).

b) 50% concluded that is a simple statement, with a purpose to intimidate the other half, thought it would be followed by action from Russian side.

c) The impact on Romania is the same as to the other allied countries (EU/NATO).

3. The most informed team was obviously the third, as it had access to a much larger fund of data and it has not been exposed to altered news or contexts by moderator.

Discussions were the longest, allowing extraction of multiple working hypotheses. Those answers having the highest correlation have been retained and recorded after analysis and validation within the group. Answers were as follows:

a) Recent statements are the continuation of older ones; all indicate a certain fret of Russia; however, such deployment of naval military troops requires large costs; Military troops are not urgently needed, Russia already having quartered military troops in Syrian port Tartus; It might possibly expand its presence in another state area (Cyprus, Libya and Egypt were mostly indicated). Most likely the West intent to intervene in Syria caused Russian statements; Russia wanted to signal not giving up on Syria and supports Assad's regime.

[I find it interesting that Egypt was mentioned, taking into account that the first news regarding possible Russian military deployment in the area, occurred in less than 2 to 3 weeks after our research, that is early November 2013][21].

[21] http://www.enational.ro/news/rusia-isi-face-baza-navala-in-egipt-348634.html/, seen October 2, 2013.

b) It is a simple statement; it will not be implemented that way; most likely Russia will maintain or increase number of troops in Syria (possible other countries in the region).

c) Inferences for Romania are not others than any EU or NATO member state. The statement has nothing to do with the announcement regarding hosting missile shield on national territory.

Question	Team no.1 – Answers:	Team no.2 – Answers:	Team no.3 – Answers:
What is Russian Federation's real purpose?	Russia wants to recover losses after Cold War; Russia wants to rebuild spheres of influence held by USSR; Russia wants to sabotage/cancel West strategic approaches (Western countries and the U. S.), namely those obtained by NATO expansion.	Russian Federation wishes to rebuild the USSR's area of influence; Russian Officer's statement shows Moscow's concern towards NATO approach to its borders; Russia wants to control trade routes crossing the Mediterranean; Russian military troops' intention is to intervene in favor of its allies (Iran, Syria).	Recent statements are the continuation of older ones; all indicate a certain anxiety; however, such deployment of naval military troops requires large costs; Military troops are not urgently needed, Russia already having quartered military troops in Syrian port Tartus; It might possibly expand its presence in another state area (Cyprus, Libya and Egypt were mostly indicated). Most likely the West intent to intervene in Syria caused Russian statements; Russia wanted to signal not giving up on Syria and supports Assad's regime.
Is it just a statement, or Russia would send troops to the Mediterranean?	It is a statement that will be implemented.	50% concluded that is a simple statement, with a purpose to intimidate the other half thought it would be followed by action from Russian side.	It's a simple statement; it will not be implemented that way; most likely Russia will maintain or increase number of troops in Syria (possible other countries in the region).
Does this deliverance/statement have an effect upon Romania?	This will cancel the strategic advantage obtained by Romania for hosting U.S. military troops, respectively, by hosting elements of the future missile shield.	The impact on Romania is the same as to the other allied countries (EU/NATO).	Inferences for Romania are not other than any EU/NATO member state. The statement has nothing to do with the announcement regarding hosting missile shield on national territory.

Every day we are exposed to such (altered) news. *The way information is shared/expounded, charisma of the one who shares the information and the way data context is exposed, are parameters/ factors influencing analysis.*

Altering one of the above parameters may forge analysis. How often the way information is exposed does not matter? The more attributes (e.g. adjectives with negative emotional charge), the more tempted we are to evaluate the situation in mainly negative registry.

How often are we not influenced by the personality of the person communicating the information? *If a person is an undisputed leader or has charisma, we tend to give credence to a greater extent, and we doubt a person we do not know or has less credibility.*

How often are we amenable to a context? *A series of negative news will make us value, by contrast, a single positive information. Drawing out from the context, exaggerated presentation of certain contexts may influence analysis of a simple information/data. "Halo" effect is true in analysis as well, and the need to obtain social consensus often leads us to accept what seems to be accepted unanimously by everybody.*

Even though our students and MA graduates were not experienced intelligence analysts, they have shown us, at some level, how analysis errors may happen.

The less experienced, the higher the noise and the lower the ability to extract the clear sound from the great mass of noises – Team no. 1. A more convenient option for us (intellectually) and socially approved will also be more rapidly accepted when it comes of a straight forward news, without any interpretation, but most often we lack accuracy and correctness of analysis.

Moreover, lacking emotional characteristics or attributes, a drily news may generate completely different approaches, polarized – Team no. 2.

The higher level of acknowledgement, expertise, amount of data on a subject and degree of freedom (non-exposure to misinformation, charismatic leaders, etc.), the higher probability to produce objective analysis. Greater interaction between senior analysts tends often to function as a true task force, cooperating and acting synergistically – Team no. 3.

For team no. 3, any attempt to change assumptions or ask new questions, with the purpose to confuse the subjects, were doomed to failure, facing a greater volume of information, the subjects suddenly became experts. Increasing awareness and multiplicity of sources of information gave team no.3 guarantee of certain objectivity of their analytical approach.

Annex 1 – News/Item no. 1

Feared Russian Navy began preparing thoroughly for the deployment of permanent troops to defend Moscow's interest in the Mediterranean, according to the Admiral Viktor Chikov's announcement dated Monday, March 11, 2013, quoted by RIA Novosti. American and Europeans would soon have Russian cruiser carriers and submarines, just like in Cold War times.

We recall that the former Soviet Union maintained a fleet in the Mediterranean from 1967 to 1992. It had the purpose to counteract the U. S. 6th Fleet during Cold War and had 30-50 warships and auxiliaries.

American airbases, including the one in Mihail Kogalniceanu Airport might lose their strategic relevance as Russian ships would neutralize American planes at any time.

"The Minister of Defense has ordered us to form a force to operate permanently in the Mediterranean" said Chirkov. "We have already begun deployment" he added.

Defense Minister, Serghei Shoigu, had said earlier that it was decided to send a permanent fleet in the Mediterranean.

"I believe we have the ability to settle and maintain such a fleet" said Shoigu, who spoke about the recent success major naval maneuvers conducted by the Russians in the Mediterranean and the Black Sea.

Exercises – true Russian military show of force, perhaps in response to the insistence of Americans and Europeans to achieve missile defense – involved ships in the fleet of the North Sea, the Baltic Sea, and the Pacific Ocean.

The two Russians officials did not mention a deadline for deploying new naval forces, which would require significant efforts in terms of logistics.

A senior official in the defense ministry had said in early March for RIA Novosti, the naval forces would consist of 10 warships and auxiliaries from three existing fleets.

The terrible Russian naval deployment may operate in the Mediterranean, using ports of Cyprus, Montenegro, Greece and Syria as supply points, according to sources.

Annex no. 2 – News/Item no. 2

Russian Navy began preparing for the permanent deployment of the naval forces in the Mediterranean, according to the announcement, Monday, March 11, the commander in charge, Admiral Viktor Chirkov, cited by RIA Novosti.

"The defense Ministry has ordered to put together a naval force to operate permanently in the Mediterranean ", said Chirkov. "We have already begun deployment", he added.

Defense Minister Serghei Shoigu, said earlier that it was decided to form a permanent naval force in the Mediterranean.

"I think we have the ability to form and maintain such a force", said Shoigu, who spoke about the recent success major naval maneuvers conducted by the Russians in the Mediterranean and the Black Sea. Exercises involved ships in the fleet of the North Sea, the Baltic Sea, and the Pacific Ocean.

A senior official in the defense ministry had said in early March for RIA Novosti, the naval forces would consist of 10 warships and auxiliaries from three existing fleets.

Annex no. 3 – News/item no. 3

(For space reasons, I will show in here only the headlines presented to Team no. 3)

Russia sends warships to Syria (Monday, November 28, 2011 at 7:37 p.m)

Russian warships headed to Syria (Saturday, January 7, 2013, at 4:32 p.m.)

Russian warships arrived in Syria - local press (Sunday, January 8, 2012, at 10.02 p.m.)

Russia plays dangerous: sends special anti-terrorist troops in Syria (Tuesday, March 20, 2012, 15:02 p.m.)

Russian naval maneuvers in the coast of Syria. Russian secret service claim that the opposition in Syria is preparing a challenge for Moscow (January 11, 2013, at 07:26 p.m.)

Russian ships bound for the Mediterranean (January 19, 2013, 11.27 a.m.)

Russian navy began preparing for the permanent deployment of naval forces in the Mediterranean (RIA Novosti, March 11, 2013)

Russia wants to relocate a permanent fleet in the Mediterranean (RM, March 11, 2013)

Russian navy began preparing for the permanent location of the naval forces in the Mediterranean Sea (Karadeniz Press, March 17, 2013)

Russia sends warships in the Mediterranean, amid imminent western attack on Syria (August 29, 2013)

Syria: Russia sending warship with a "special load" (Friday, September 6, 2013, at 07.14 p.m.)

Bibliography

1. Gill, Peter; Marrin, Stephen; Phytian, Mark, *Intelligence theory: Key Questions and Debates*, Taylor and Francis, Studies in intelligence series, 2008.

2. Heuer Jr., Richard J., Psychology of Intelligence Analysis, Center for Study of Intelligence, Central Intelligence Agency, 1999.

3. Heuer Jr., Richards J.; Pherson, Randolph, *Structured Analytic Techniques for Intelligence Analysis*, CQPress, Washington D. C., 2011.

4. Johnston, Rob, *Analytic Culture in the US Intelligence Community*, Center for the Study of Intelligence, Washington, 2005.

5. Maior, George Cristian; Nițu, Ionel, Ars Analytica, Editura RAO, București, 2013.

6. Nițu Ionel (coord.), *Ghidul analistului de intelligence, Compendiu pentru analiștii debutanți,* Editura ANIMV, București, 2011.

7. Nițu, Ionel, *Analiza de intelligence. O abordare din perspectiva teoriilor schimbării*, Editura RAO, București, 2012.

8. Taleb, Nicolas, *Lebăda neagră. Impactul foarte puțin probabilului,* Editura Curtea Veche, București, 2008.

Mrs. Maria Magdalena Grigore graduated The Academy of Economic Studies – Faculty of International Economic Relations in Bucharest, geopolitical and geostrategic specialization, and since 2013 she is MA within the Management of National Security Intelligence Program at National Intelligence Academy "Mihai Viteazul". She served in different political and administrative functions, occasions to encounter the issue of national security and international relations, especially as TRACECA National Secretary appointed at the Ministry of Transport, representing Romania in this regional and international cooperation forum. In 2008 was appointed as manager of Romanian National Company of Motorways and National Roads and previously administrator within the National Airline Company TAROM. As a representative of Romania, she claimed several presentations at international conferences on the restoration of the old Silk Road and promotion of cooperation opportunities in the corridor Europe-Caucasus-Asia.

Intelligence for competitiveness and national security in the knowledge society (I)

A short benchmarking analysis on the creation of a Romanian national intelligence system

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Abstract

With the transition to the knowledge economy, the value of all social, organizational and individual entities is directly dependent on its intellectual and knowledge capital. Unfortunately, the majority of decision-makers focus too much on the tangible assets, almost to the point of ignoring the intangible ones. However, in order to successfully navigate this world, where the global is directly connected to the local it is essential, to first understand the interaction between certain key-concepts, such as politics, economy, knowledge, intelligence, strategy, competitiveness and security.

In the new evolution paradigm knowledge means value, while intelligence means power, that is why the paper analyzes the evolution of national intelligence systems in an attempt to shed some light on the interaction models employed at international level, which can then be adapted an re-configured to fit the necessities of developing countries, willing to engage in such a national endeavor.

To develop a national intelligence model applicable for Romania, the study employs benchmarking analysis to compare the structure and performance of various national intelligence systems and extract those structural elements that fit the overall approach to continuous improvement. To insure the efficiency of the results, we have selected for the comparison leading examples of national intelligence systems: the US, France, Great Britain, Canada and Germany.

The analysis resulted in a set of guidelines and best practices that, after integration can be used to elaborate a blueprint for the development of a Romanian national intelligence system by both decision-makers and representative of the academia and private sectors. This research product is by no means comprehensive, as there are many other case studies that could and should have been included in the benchmarking analysis, in order to create a full picture of the overall evolution undergone by states in the process of developing national intelligence systems.

Though the issue of national intelligence system has been debated before, both in the academia and at governmental level, as proven by the existence of the Carayon Report and the works of Robert Steele, this has always occurred in large states, with a strong tradition in the field. The originality of this paper it that is uses benchmarking to try to understand the processes taking place in all those places and then extract key elements and patterns that then can be re-adapted and replicated for a different type of state, such is the case of Romania.

Keywords: national intelligence model, competitiveness, national security, Knowledge Society, knowledge capital

Introduction

"We are a smart people, but a dumb Nation and this is something we must be aware of if are to prosper and be secure in the 21 century"
(Steele, 2000:80)

National intelligence is produced to ensure national security, a concept defined at the political level, but having its foundations in knowledge intelligence. We can, therefore, conclude that the manner in which the concept of "national security" is defined plays an important part in the development of a national intelligence system/process.

In the last two decades the open systems and open sources field (OSINT) has known an unprecedented evolution. That is why it is important to address OSINT separately from the intelligence collected from covert sources. Such a model would support the theoretical and practical development for both areas of intelligence, enabling OSINT to integrate in the domestic informational cycle of the state. In the same time the covert intelligence becomes a client of OSINT, being unburdened by the efforts OSINT is currently making.

If we were to make an analogy between genetics and the intelligence cycle there are several interesting aspects, which draw our attention. In the case of living organisms, there are two information processing systems, one which works in the background, developing the characteristics of the species and one which works in plain sight comprising those activities, which appear as a response to or anticipation of events taking place in the external environment[1].

[1] A. Fedanzo (1993) A Genetic View of National Intelligence. *Second International Symposium: National Security & National Competitiveness: OPEN SOURCE SOLUTIONS Proceedings*. volume I. p. 6-14. [Online]. Available from http://www.phibetaiota.net/1993/12/1993-fedanzo-a-genetic-view-of-national-intelligence/, p. 6-14.

Redefining national intelligence systems, in a context marked by the end of the Cold War, is characterized by processes, which take into account both the national and global features, processes that are controllable and often sequential. The concepts of reform, transformation and/or revolution in intelligence or revolution in intelligence affairs[2] are employed most often to depict the complexity of changes taking place at the human, institutional and conceptual levels. The objective of these changes consists in the formulation and acquisition of a new ability – the adaptability to an ever changing environment. This is the only way for any social entity to gain competitive advantage. This paper uses benchmarking analysis to study the transformation that has marked the evolution of national intelligence systems, in the last decades, focusing on several significant case-studies such as the US, Canada, France and the UK.

National intelligence units

To be able to conduct a comparative analysis of the national economic intelligence units this study employs a four-tier scale analysis entitled PEKS (P – Political, E – Economic, K – Knowledge and S – Security), layers that must be general and invariant (meaning, a supplementary analysis is needed to show that these tiers are encountered in each national system from the set under analysis). In this study, however, we will limit ourselves to a global analysis, though it is important to note the invariance (in terms of time, it lasted for tens of years) of the institutional structure, mixed with the flexibility necessary for the adaptation of the entire system.

Note that none of the descriptions of national intelligence units mention a platform for the management of human capital production albeit, if we were to study more carefully the cases under analysis, we would notice that each of these units made this their main strategic goal. The moral of this discovery is that, in terms of creating human capital no out-sourcing is employed and only the final institutional product is put forward to be debated upon.

Although, the phrase "economic intelligence" seems to be rooted in a national intelligence context, it is actually built in an interdisciplinary manner. The economic is a means to ensure security understood as sustainability, a necessary means for the value system through the capacity required to gain competitive advantage, a means and not an end in itself.

[2] D. Barger (2005) *Towards a Revolution in Intelligence Affaires*, RAND Corporation, National Security Research Division. [Online]. Available from http://www.rand.org/content/dam/rand/pubs/technical_reports/2005/RAND_TR242.pdf, p. 33-47.

It is vital to understand that through the very use of comparative analysis methods, a process of convergence takes place at the structural and functional level of various national intelligence systems, which the states that do not possess the wisdom to prepare in advance for this evolution will be unable to understand.

Besides, the reason behind the need to understand such national systems is that we must possess a good knowledge of the main trends first and then of the fluctuations (for the simple reasons that it is the trends which define the fluctuations in both statistical and cognitive terms). It would be an unforgivable error to accept that Romania is a small country and Romanians are not ready to face the future. Romania is not a small country inside the EU, and in order to have Romanians prepared tomorrow, people should have started yesterday to think about how to prepare them today.

The cases analyzed in this study are those of the US, France, Canada, Great Britain, Germany, and Japan. Mapping the level of knowledge in intelligence across the world is maybe one of the most important resources for any intelligence-related activity.

Case Study: the US

The beginning of the 90s in the US was the period of momentous transformations in the field of intelligence as a result of several facts: Robert Steele's redesign of the role of open sources and the creation of the "Smart Nation" concept – a movement that originated inside the Intelligence Community[3] and was aimed at ensuring access to open information and later to education, the economic intelligence initiatives, all taking place in the context of the end of the Cold War.

Robert Steele's movement and the transformation it brought contributed to the process of redefining the Euro-Atlantic area in the new political context as the European states identified and implemented the imported conceptual mechanisms of the new paradigm

Even if it is not recognized today by the intelligence establishment the OSINT conferences taking place in both the US and then Europe provided the setting for disseminating to the American and European public information on the new field of intelligence, irrespective of the fact that the

[3] An example is the creation in 1995 of COSPO (Community Open Source Program Office) inside the CIA.

audience belonged or not to the intelligence community. The first such conferences were organized by the OSS and Steele's website www.oss.net was for many of the first unrestricted contact with the intelligence field and the first step in the diffusion process of the intelligence culture.

In terms of institutional building the initiative of retired Marine Corps officer James P. Etter of creating in 1991 the American Military University, an establishment which has become a symbol of the intersection between the civil and military worlds, with the academia acting as the main catalyst, was one of the most important stages of the process.

In the new political context, intelligence-related initiatives have multiplied, ensuring a good representation of American strategic intent in non-military terms. What comes out of this is a network of interconnected institutions defending American interests in the economic and non-economic areas.

Therefore, an analysis of the transformations undergone by the American Military University between 1991 and 2004 reveals the sequencing and controllability of the entire process:

I. The research and preparation stage lasted for two years, starting with 1991.

II. The preliminary operations stage took place during a three year period, having national accreditation as the end-goal.

III. Maturation lasted for three years, 1996-1998; note that in 1996 Steele launched the "Smart Nation" concept.

IV. Growth lasted for three years, 1999-2001.

V. Expansion and Diversification lasted for three years, 2002-2004.

The American Military University is a solution fully able to solve the problem of integrating the civilian and military dimensions inside an intelligence/OSINT culture with the help of the academic intelligence concept[4]. The project is envisaged to continue until 2015 as the entire academic system is currently undergoing a transformation that would enable it to provide a nationwide integrated solution.

[4] In U.S. political culture the civil-military relations were conceived in the democratic state framework, being a continuous research subject D. B. Bobrow (1996), The Civic Role of the Military: Some Critical Hypotheses, *The Western Political Quarterly*, 19(1), pp. 101-111 and O. R. Holsti (1998), A Widening Gap between the U.S. Military and Civilian Society? Some Evidence, 1976-96, *International Security*, 23(3), pp. 5-42. In the post-Cold War decades it became a central dimension for both NATO new membership and security affairs as seen in P .D. Feaver (2003), *Armed Servants. Agency, Oversight, and Civil-Military Relations*, Massachusetts: Harvard University Press and H. Born, M. Caparini, K.W. Haltiner, J. Kuhlmann (2006), *Civil–Military Relations in Europe Learning from crisis and institutional change*, Routledge, New York: Taylor & Francis Group.

A current example is given by a report from the Defense Science Board (2014), which found there are "gaps" in the U.S. intelligence community's "global nuclear monitoring" capabilities. It argued that closing these gaps "should be a national priority." The report recommended adopting "new tools for monitoring," including looking at "open and commercial sources" with "big data analysis".

"In some cases, this problem is partly due to a lack of careful scholarship, which requires an awareness of the limitations of the available knowledge, an understanding of how far one can go in drawing conclusions from it, and a willingness to ask tough questions about those conclusions to see how well they hold up to scrutiny. But these gaps and failures are also the product of an institutionalized deficiency in the way the U.S. government recruits and trains intelligence analysts. "[5]

The network of public institutions supporting the national intelligence system has been expanded through partnerships with the public and private sector and a process of externalization aimed at increasing capacity in key areas is underway. An example of these evolutions is the relation established between the Central Intelligence Agency and In-Q-Tel, a non-governmental non-profit organization having the mission of investing in technologies that may prove useful for the technological needs of the US Intelligence Community.

The US structure is designed around what we may call "the Vannevar Bush paradigm" comprising:

- the micro-macro relations between the P component (the white colored area) and the rest of the system; in practical terms, the White House has a representation of the system (unchanged from 1947) and also a responsibility for the political power;
- the S component (the yellow colored area) is fully integrated in the other components through information fusion and decision configuration mechanisms; it acts in practice as an interface between the first component and all the rest, being endowed with the attribute of national security;
- the C component (the green colored area) is from the start designed to integrate the defense economy and civilian economy types of knowledge. One of the institutionalization elements resides right inside the NSF (National Science Foundation, which does not appear in the figure);

[5] G. Kulacki (2014) Defense Science Board off point open source intelligence reform, Union of Concerned Scientists. [Online]. Available from http://allthingsnuclear.org/ defense-science-board-off-point-on-open-source-intelligence-reform/ [Accessed: 10th January 2014].

● the E component (the violet colored area) has an explicit hegemonic orientation in the framework of the democratic peace theory. It is orientated towards the outside, because domestic welfare is highly dependent on external performance - the welfare at home is achieved with the help of capital imported from outside (this meaning much more than just commerce and the tangible economy);

● the portals component (the blue colored area) is the correspondent of Vannevar Bush's MEMEX idea, represented through the concept of virtualization inside the national intelligence system.

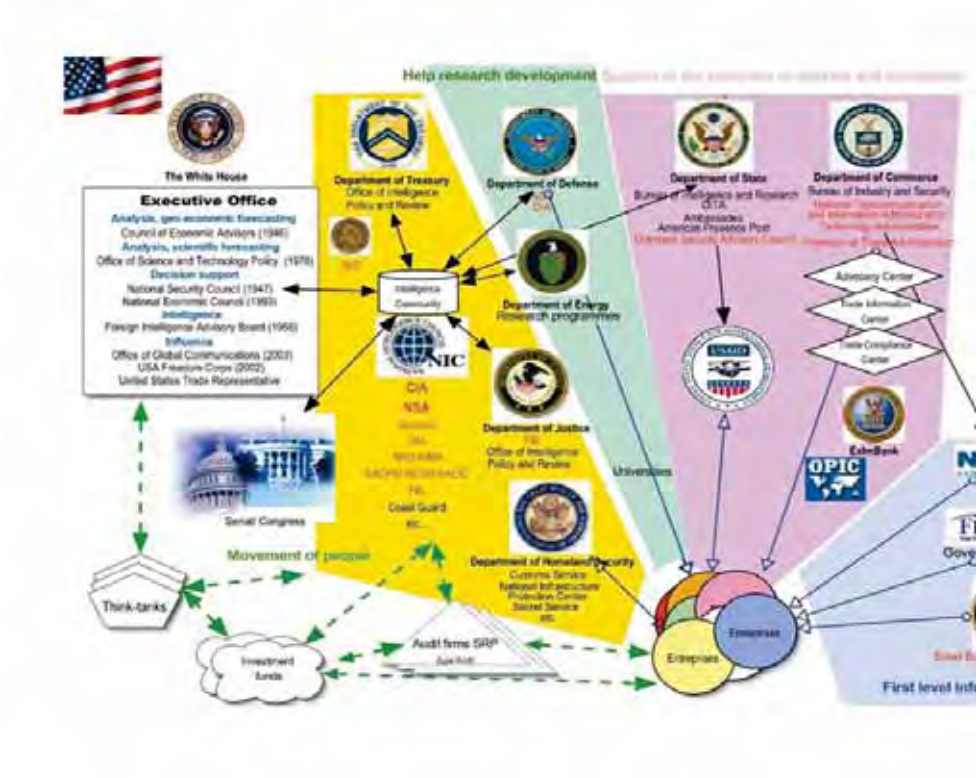

FIGURE 1 – The US National Intelligence System
(Carayon, 2003, Annex 3)

All these elements show us that the system in question is highly flexible being designed for economic warfare conducted inside the paradigm "intelligence is knowledge and knowledge is power". Moreover, following

a knowledge transfer, which has taken place in the last 50 years two phenomena occur: firstly, the philosophy behind this architecture provides the matrix for all other national intelligence systems and secondly, the system must be made more flexible so as to ensure competitive advantage.

The element left unexplained is the training platform, which has been reduced to universities and the "circulation of human resources", while another key element is the positioning of the "influence" component inside the White House, influence being a fundamental factor in the functioning of the national intelligence system.

Currently, the process of making the system more flexible is undergoing a structural transformation in accordance with the "smart nation" paradigm through the:

a. extension of virtualization – the AMU project has provided the first university that integrates the skills of military and civilian systems on a 100% online platform; this achievement is not prolonged with the "knowledge democratization" process – the creation of a meta-platform fed by the main universities

b. extension of the OSINT paradigm inside the EU – the EUROSINT project for example is a replica of the AMU's development project;

c. preparations made to develop the theoretical framework necessary for the development of the intelligence field;

d. measures aimed at setting the stage, with the help of the ideas related to the creation of national intelligence systems, for a new understanding of citizen roles – moving towards the vision of the citizen as intelligence consumer (eg. the "lifelong learning" concept fits this new type of paradigm).

Case Study: France

In the beginning of the 90s, as a domestic reaction to the global challenges and through the import in a more or less open manner of the conceptual models that have provided the theoretical basis for the transformation the American intelligence system, France started its own project of redefining its national intelligence system. The main fields of action for the French were the academic, economic and territorial levels. Consequently, a higher education institution was founded dedicated to the means and practice of "economic war". Moreover, a national network of public and private institutions was created to manage the theoretical and

practical issues connected with the intelligence field. The French approach was openly oriented towards an intelligence culture and a realistic insight into the problems concerning the statecraft future sustainability[6].

What distinguishes the French project is its centralized character, in agreement with the French political philosophy. Therefore, starting from this background and the existent institutional framework (developed throughout the entire country) the concept of territorial intelligence[7] is defined as a supplement to that of economic intelligence.

Each of these three initiatives becomes a guiding axis for this study. Two additional clarifications come to strengthen the idea of a sequential and controllable process in what concerns the creation of the French national intelligence system.

Thus, an analysis of the stages undergone by the French intelligence system between 1989 and 2004 show us the sequential and controllable character of the process:

I. 1989-1991 – Identification of the problems through academic debates among experts (the studies of Bernard Naboulek, Christian Harbulot and Philippe Baumard);

II. 1992-1993 – Creation of an analysis group addressing the topic of "economic intelligence and enterprise strategy" within the General Planning Commissariat, under the presidency of Henry Martre;

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[6] e. g. "Even during the Cold War, getting intelligence in economic, technological, and industrial matters from a country with which you are allied is not incompatible with the fact of being allied. The competition in terms of technology and commerce and industry is stronger than it was during the Cold War. There should be more emphasis put on that, and on industrial espionage", quoted in Schweizer, Peter. *Friendly Spies: How America's Allies Are Using Economic Espionage to Steal Our Secrets*, New York: The Atlantic Monthly Press, 1993.

[7] The relationship between territory and political science was initiated as a landmark of the French political culture through the contributions of André Siegfried (1875-1959), the founding father of electoral geography and the corresponding analysis methods e.g. A. Siegfried, Le Canada et l'impérialisme britannique, p. 3-58 in A. Siegfried, P. de Rousiers, M. de Périgny, F. Roz, A. Tardieu (1911), *Les questions actuelles de politique étrangère dans l'Amerique du Nord*, Paris: Librairie Félix Alcan; A. Siegfried (1913), *Tableau politique de la France de l'Ouest sous la Troisième République*, Paris: Armand Colin; A. Siegfried (1954), *Tableaux des États-Unis*, Paris: Armand Colin, etc. Some other two facts are relevant on this ground. First, it is noteworthy that this approach is highly different of geopolitics, classic or modern; this aspect was treated in a course of S.G. Sebe, Analytical Spatial Theories in Political Science, Faculty of Political Science, University of Bucharest, 1998-2000 (unpublished). Second these approaches are included in the class of research methods in political science; one example particularly relevant for Romania is Matei's PhD thesis, S. Matei, Romania at voting age: 18 years of electoral change in post-communism, Lambert Academic Publishing, 2012.

III. 1994 – Publication of "Martre Report" comprising several proposals, such as:

a. assessing the potential of existent skills and information networks at national and regional level;

b. defining the necessary structures and means to create networks;

c. introducing common procedures.

IV. 1995 – Creation of the "Competitiveness and Economy Security Committee": seven key figures elected based on their experience, authority and competences in the field of economic intelligence for a period of 3 years with the clear objective of providing decision support to the Government in regard to competitiveness and economic security issues and of providing advice in the elaboration and implementation of policies in the field, thus ensuring continuous coherence and coordination of all actions taken.

V. 2003 – Publication of the "Carayon Report" on economic intelligence, competitiveness and social cohesion;

VI. 2004 – Creation of the General Delegation for Economic Intelligence inside the Ministry of Economy and Finances;

VII. 2008 – The White Book of Defense and National Security launched by the French Presidency of Sarkozy that tries to integrate all previous initiatives in a national intelligence system

VIII. 2009 – The official launching for the DCRI (Central Directorate of Interior Intelligence) and the creation of the DDRI (Departmental Directorates of Interior Intelligence).

IX. September 2009 – the adoption of a decree creating an inter-ministerial delegate for economic intelligence place under the coordination of the General Secretariat of the Economy Ministry. It has the mission of elaborating and promoting public policies in the field of economic intelligence and evaluating their efficacy[8].

The national network of public institutions supporting the national intelligence system was expanded through partnerships with private and non-governmental organizations (from lobby groups to reputation management NGOs) that act inside the European Union, most often in Brussels, having as a main goal – the defense of French interests. Such an example is represented by the relation between Compagnie Européenne d'Intelligence Stratégique (CEIS) and EUROSINT Forum.

[8] C. Countenceau, F. Barbara, W. Everett, A. Gilliéron, X. Jacquin, M. Poullain, C. Valle and E. De Vigouroux D'Arvieu, (2010), *Guide Pratique de l'Inteligence Économique*, Paris: Eyrolles, p. 4.

The main successive stages undergone by France in the process of defining a matrix for its national intelligence system, covering the period between 1994 and 2008 have already been mentioned in the beginning of the paper. There are, however, several important accomplishments of the Carayon Report, from which a lot can be learned when implementing a Romanian model. First, the design of the French system employs a state-centric approach, which brings it closer to Romanian traditions in the field. Second, the mentality of the French elite is of a Socialist orientation (following the European Socialist tradition and not the Russian one), which makes a radical transformation impossible. For the abovementioned reasons we will now proceed to show, which elements of the US design lack from the French model, thus indicating the distinct mark of Henri Martre.

The missing institutional components could not be included inside the already existent institutions due to the mentality problems already mentioned, therefore after being identified they were institutionalized separately (this was the case of the "École de guerre economique" and other similar institutions).

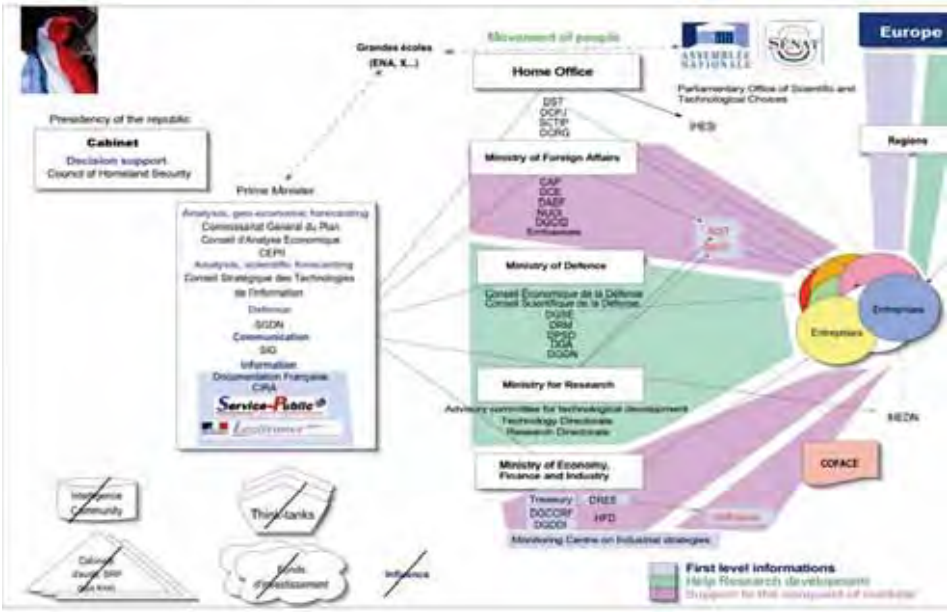

FIGURE 2 – French National Intelligence System
(Carayon, 2003, Annex 6)

The integrating link between the defense and civilian economies is preserved (the green colored area), acting as in the American case as the originating factor for the OSINT community. The orientation towards hegemony is preserved (the violet colored area). Furthermore, the decision support dimension was ensured through the creation of the French economic rating agency COFACE – Compagnie Française d'Assurance pour le Commerce Extérieur.

The traditional French approach on territoriality was re-conceptualized because of the fact that the nearest region is the European Union. Thus, the entire concept was extended through a system similar to territorial and informational early warning. Key positions to place the drivers of change were identified inside the newly created institutions (ADIT – Agence pour la Diffusion de l'Information Technologique, INIST – Institut de l'Information Scientifique et Technique and UbiFrance), designed to flexibilize the system without changing it radically structurally. For example, the great schools, which have provided France its elite for over 200 years (École de Mines, École Normale Superieure, École Polytechnique şi École des Affaires) have remained in place.

Case Study: Canada

The case of Canada is the most important for our analysis because the Canadian national intelligence system was not designed and implemented for hegemony, Canada not being in the position to claim such a status. Furthermore, Canada has a partnership with the US and the EU in the field of intelligence, being one of the most important contributors to the debates on how to make the system more flexible (through the development of intelligence education systems and building a theoretical framework for intelligence).

Canada's behavior is one of discreet intervention in all fields of activity, being oriented mainly towards the external environment and knowing not only how to strengthen its reputation, but also the best ways to capitalize on it.

The Canadian national intelligence system is an offensive one, designed not only for economic competition but also for "knowledge wars".

In what concerns the design of the Canadian intelligence system the following elements bear notice:

The component dedicated to traditional security (the yellow colored area) is part of the intelligence community and provides decision support solely to the federal government.

The research-development component is distributed between the conquest of markets module (the violet colored areas) for the Applied Research and Commercial Research tasks and the civil society organized as a forum of NGOs for the Fundamental Research and Applied Research tasks.

Although the figure does not include a knowledge production system, we must take into consideration that Canada has a certain particularity, which consists in the integration of think-tanks in the decision-making processes, be it governmental or private. The early warning component is explicitly connected to the concept of opportunity and integrated into the conquest of markets module (in violet).

Another particularity of the Canadian system is the fact that it reunites all professional organizations in a mixed module, which combines market conquering activities with intelligence-related ones (one of the first systems in the world in which the economic sector is conceived as the analogue of a unit engaged in war)

The Canadian intelligence system is practically designed for discretion and integrated action.

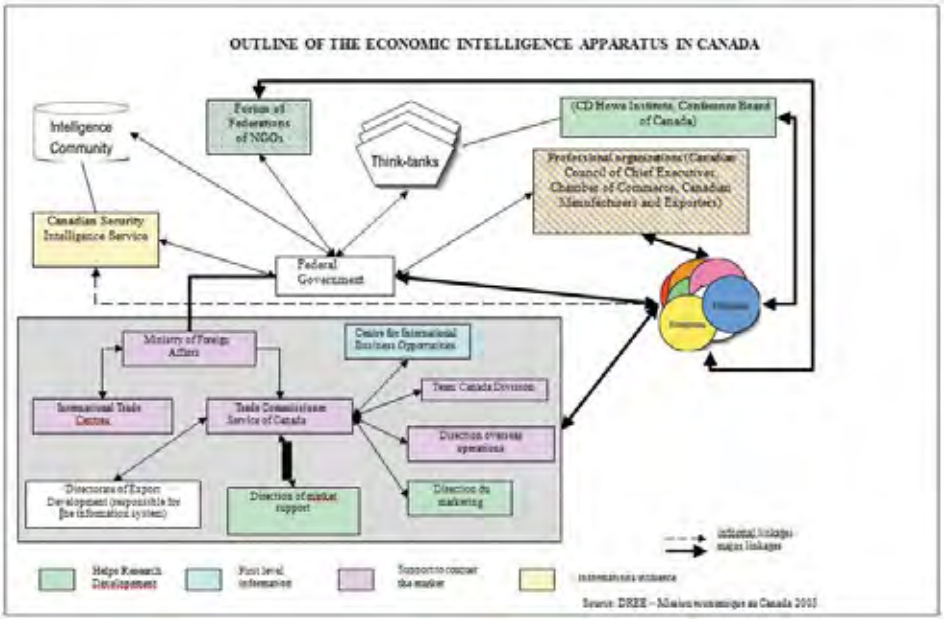

FIGURE 3 – Canadian National Intelligence System
(Carayon, 2003, Annex 7)

Case Study: Germany

The German case also provides a good study model. The intelligence and influence activities (the yellow colored modules) are conducted by a system explicitly designed for such a purpose as well as by labor syndicates (the OSINT analysis leads to such a conclusion) and through the German intelligence service – the BND. Moreover, these categories of activities are distributed in all the other societal components, from NGOs to the press, large private conglomerates, diplomats etc.

A distinct feature of the German system is its mixed character, which is much more striking than in the case of Canada. In addition to the above mentioned the first referral information are distributed both through the corporate component and through the professional organizations.

Germany's federal structure is transformed in this figure in a criterion for the segmentation of the other modules. For example, the support for research activities is given directly by the lands through universities that integrate fundamental, applied, practical and commercial research activities. Strategies have been initiated at national level to increase the integration of universities, research centers and corporations. For example, in Karlsruhe a technological institute was founded in 2009, which brings together the skills portfolio of the Universität Karlsruhe and the Forschungszentrum Karlsruhe.

The orientation towards the conquest of markets is driven by the intelligence activity conducted by the banking system combined with the financial consulting and corporate sector.

The model does not include the analog of the French COFACE, namely HERMES, Germany's rating agency (a project conducted by the University of Ilmenau during 1993-2000 and then transferred to federal level).

The German intelligence community is one of the most advanced in Europe and one of the most relevant indicator of its success is the activity of the Springer Publishing House in Berlin, which in the last 10 years has coordinated several book collections dedicated to intelligence, the majority of which are not translations works written by foreign authors, but are books by German authors; therefore though the German intelligence community is not as vocal or as visible as other intelligence communities in Europe and in the world, the skills it possesses make it a very competitive European actor.

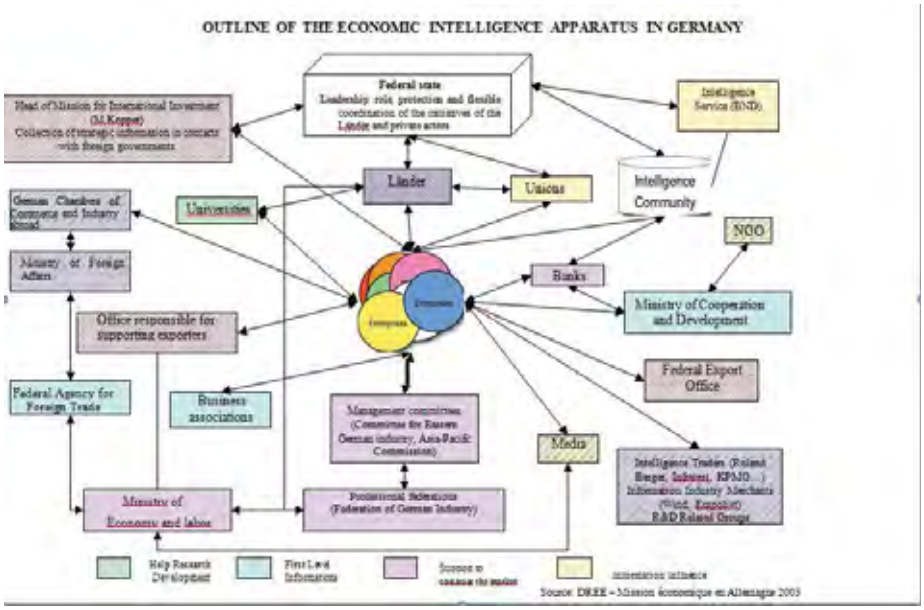

FIGURE 4 – German National Intelligence System
(Carayon, 2003, Annex 7)

Case Study: Great Britain

The national intelligence system from Great Britain is the only intelligence system with the corresponding community directly inserted on the external market, which is perfectly understandable given the colonial past of the country. It is the system, which is the most connected to the US intelligence, having enjoyed for the past 50 a symbiotic relation with it.

The intelligence activity functions in the global network through 3 modules: that of intelligence services, the BI compartments (their tradition comes from William Petty in 1960 and the maritime insurance companies) and the Commonwealth's Foreign Ministry and its system embassies.

The financial-banking systems are basically mixes between the intelligence activity, the conquest of markets and the intelligence community.

The NGO systems are sensors and analyzers (according to Waltz's model of informational warfare) for first referral information and decision support for the rest of the system.

The influence systems are distributed through the central concepts of club and lobby, which generate an incredible variety of institutions present in all social segments both inside the country and in the old Commonwealth.

Traditional think-tanks have always filtered the fundamental and applied research, produced by universities and institutes in a format useful for the process of decision-making in the government, corporations or military institutions. This should draw attention to the psychological profile of those trained in these institutions.

Several British institutions have training and selection criteria for professions which demand first and foremost professionalism and as this was applied as a state policy for long periods of time it statistically lead to remarkable results, which become indisputably reputation bearers.

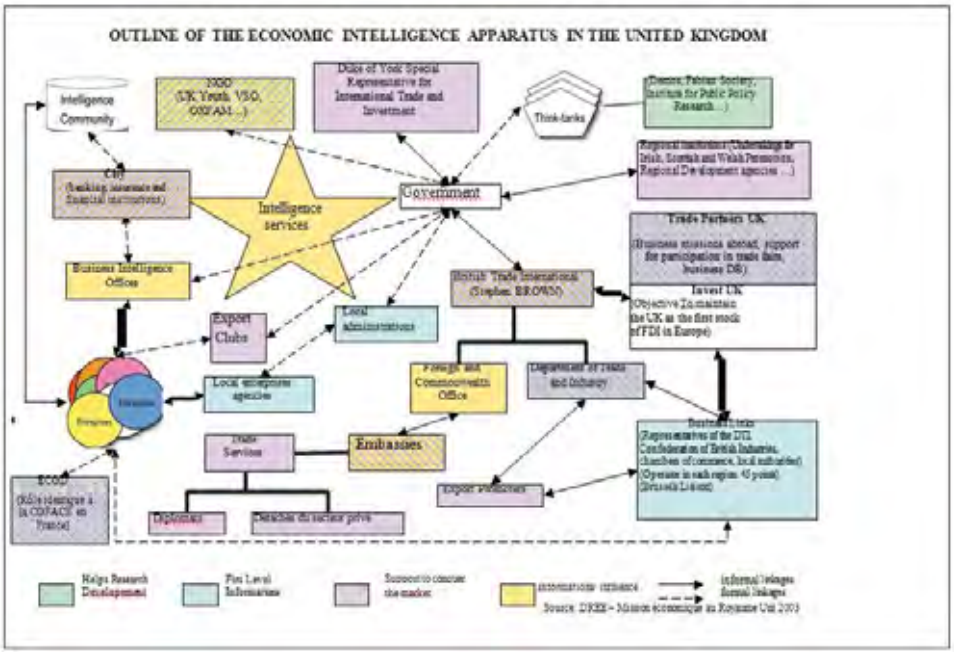

FIGURE 5 – British National Intelligence System
(Carayon, 2003, Annex 7)

Japan

The case of Japan deserves special consideration because of several factors:

It is the only national intelligence system organized dynamically, not in a sequential network, but in a static one, so that it allows adaptable virtualization.

This characteristic is the result of two factors. The first is the PDCA cycle (Plan, Do, Check, Act), a cycle defined by Deming for industrial production processes from the 50s and the second is the management principles formulated by Drucker (in the same period, during their time in Japan). Their synthesis in terms of political marketing intelligence combined with the Japanese value system has led to this outcome. As the PDCA[9] and OODA[10] cycle are symbiotic, the conceptual structure of management places the architecture of such a system on a special position giving it a level of flexibility, which allows dynamic adaptation to take place.

Therefore, the Japanese designed extended the PDCA cycle from one of industrial production as component of the tangible economy to an organizational intelligence cycle[11]. As we can notice the diagram includes all fundamental elements of the Japanese system. These elements are placed on an information platform (represented by the star-shaped pentagon in the center) which ensures the dynamic update of the information. The micro/macro characteristic confers informational cohesion and interoperability to the system. Furthermore, Japan has the only national intelligence system with a micro/macro accumulation, meaning that knowledge accumulation at the level of the company's functions by the same logic as knowledge accumulation at state level. The added value consists in the transformation of information in intelligence at the level of each organization.

Similarly to the British case, JETRO (Japan's External Trade Organization) integrates together with the professional federations the intelligence and conquest of markets functions, the two acting as the dynamic components which organically tie the two functions.

Another fundamental characteristic is the fact that the first referral information are often to be found in the scientific field, especially as a result

[9] PDCA – Plan, Do, Check, Act – model elaborated by Dr. Edwards Deming, the father of modern quality check and Walter Andrew Shewhart.

[10] OODA – Observation, Orientation, Decision, Action – the OODA cycle elaborated by John Boyd.

[11] In accordance with Wilensky's theory (1967), where the main feature is the integration of the governmental and corporate components to acquire competitive advantage for the nation-state.

of the fundamental and applied research processes in their early stages. This gives the system good prediction capabilities.

As mentioned before, the orientation toward hegemony manifests itself in the Japanese case not only in the economic field, but also in what concerns the universities and research institutes focused on the study of foreign markets (as each entity from the domestic markets has a clearly established position due to the dynamic accumulation mechanisms).

The syndicates are integrated into this cycle, being given decision-making powers. Through this the designer of the Japanese system wishes to acquire a certain dynamic social cohesion inside the system. The banks are conceived as integrating factors for the first referral information and conquest of new markets-related processes. The SMEs are in touch with the think-tanks through a separate regulatory channel, profiting with their help by the activities conducted by JETRO.

The state is, in reality, given a coordinator role for all scientific information, differentiating between the intelligence cycles of the corporations and the intelligence resources of the system. The analysis of this system is important not only because of its similarities with the OODA cycle[12], but also because of its dynamic nature.

Initially, the Japanese experts active in the field of marketing intelligence designed the intelligence capabilities of the large Japanese corporations and the solutions they provided led to the genesis of the Japanese national intelligence system.

[12] That in the meantime has become a research topic in the Euro-Atlantic area.

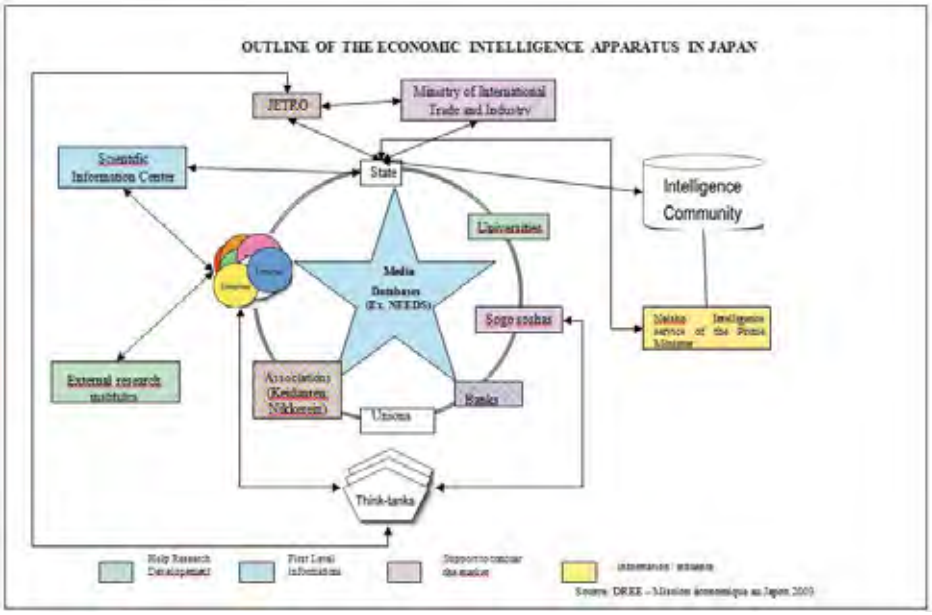

FIGURE 6 – Japanese National Intelligence System
(Carayon, 2003, Annex 7)

Bibliography

1. BARGER, D. (2005) *Towards a Revolution in Intelligence Affaires*, RAND Corporation, National Security Research Division. [Online]. Available from http://www.rand.org/content/dam/rand/pubs/technical_reports/2005/RAND_TR242.pdf [Accessed: 10th January 2014].

2. BOYD, J. R. (1976) *Destruction and Creation*, US Army Command and General Staff College, [Online]. Available from http://goalsys.com/books/documents/DESTRUCTION_AND_CREATION.pdf [Accessed: 10th January 2014].

3. CARAYON, B. 2003 "Intelligence Economique, competitivite et cohesion sociale", Paris: La Documentation française,, [Online]. Available from http://www.ladocumentationfrancaise.fr/var/storage/rapports-publics/074000410/0000.pdf. [Accessed: 10th January 2014].

4. COUNTENCEAU, C., BARBARA, F., EVERETT, W., GILLIÉRON, A., JACQUIN, X., POULLAIN, M., VALLE, C. and DE VIGOUROUX D'ARVIEU, E. (2010) *Guide Pratique de l'Inteligence Économique,* Paris: Eyrolles.

5. FEDANZO, A. (1993) A Genetic View of National Intelligence. *Second International Symposium: National Security & National Competitiveness:*

OPEN SOURCE SOLUTIONS Proceedings. volume I. p. 6-14. [Online]. Available from http://www.phibetaiota.net/1993/12/1993-fedanzo-a-genetic-view-of-national-intelligence/. [Accessed: 10th January 2014].

6. KOTLER P. and SINGH R. (Winter 1981) Marketing Warfare in the 1980s. *Journal of Business Strategy*. vol. 1. Issue 3. p. 30-41.

7. KULACKI, G. (2014) *Defense Science Board off point open source intelligence reform*, Union of Concerned Scientists. [Online]. Available from http://allthingsnuclear.org/defense-science-board-off-point-on-open-source-intelligence-reform/ [Accessed: 10th January 2014].

8. ROTHBERG, N. H. and ERICKSON, G. Scott (2005) *From Knowledge to Intelligence*, Elsevier,.

9. STEELE, R .D. (1996) Creating a Smart Nation: Strategy, Policy, Intelligence, and Information. *Government Information Quarterly*, vol. 13(2). p. 159-173.

10. STEELE, R. D. (1996) Smart Nations: Achieving National Security and National Competitiveness in the Age of Information. *Bulletin – American Society for Information Science*. 23, (1). p. 8-10.

11. STEELE, R.D. (2000), *On Intelligence: Spies and Secrecy in an Open World*, Fairfax, VA: Armed Forces Communications and Electronics Association.

12. WILENSKY, H. L. (1967) *Organizational Intelligence: Knowledge and Policy in Government and Industry*, California: Basic Books.

13. WILENSKY, H. L. (2002) *Rich Democracies: Political Economy, Public Policy, and Performance*, California: University of California Press.

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Terrorist press – Inspire magazine

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"Terorism is a product of freedom , particulary freedom of the press"
Brian Jenkins

Abstract

Mass media and terrorism are two intertwined phenomena which inevitably gave birth to a "marriage" from which both sides benefit. For several decades terrorist networks have learned to use media to induce fear or to attract new supporters and adherents. Innovative and open to change, terrorist groups have shifted part of their media in the virtual and online environment.

This paper is a qualitative and subjective analysis of the most successful terrorist publications in the Inspire magazine. Inspire magazine is a current online publication issued by the Al Malahen media foundation in 2010.

The main aim of this paper is to analyze how the objectives proposed by the editors are found throughout the content of the magazine. From the methodological point of view, this work is based on a content analysis tool through which we analyzed the ten issues of the magazine. In our analysis we took in consideration four indicators: the magazine sections, the authors, the images and the overall tone of the articles.

Keywords: terrorism, mass media, Inspire magazine, qualitative analysis.

The evolution and progress generated by the media and the advent and popularization of the Internet has led to changes in the way in which terrorist groups regard the media. Terrorists have observed that the mass media and the internet are fields of influence for every XXIst century individual so that they began to see it as a vehicle for achieving their

objectives. The importance of the media in this process is confirmed by the current leader of the terrorist network Al-Qaeda, Al Zawahiri, who estimated that more than half of the battle between believers and nonbelievers is taking place in a "battlefield" created by the media[1].

Glimpsing the interdependent and symbiotic relationship between them, terrorist organizations have learned to use the media to spread fear among a target group to attract and mobilize supporters or to undermine the ability of governments to ensure the safety of their citizens."The marriage" between the two is translated in terms of advertising and audience: terrorists need publicity and the media needs viewers and, therefore, audience. The effects of this marriage are significantly positive. Through countless news articles about them, terrorist groups succead to spread fear or sympathy in the audience.

The means by which terrorist organizations use the media are different. Whether they use newspapers, television or virtual environment interventions they reinforce once again the conclusion of the researcher Brian Jenkins who at a certain point said that"*terrorism is a product of freedom, freedom of the press particularly"*.[2]

Based on these aspects, the present approach represents an analysis of one of the most successful publications promoted by terrorist networks- *Inspire magazine*. Inspire magazine is promoted under the auspices of Al Qaeda in the Arabian Peninsula and since 2010 arrives in the hands of English readers from all over the world through the internet.

This paper is an analysis of how the objectives of the editors are found in the content. Through this approach we try to demonstrate once again that freedom of the press and the globalized world in which the Internet is a natural part of every individual's life, leads to the spread of radical ideas and also to the attraction of new supporters and followers for that group.

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[1] The original quote is *"more than a half of this battle is taking place in the battlefield of media.*"Fawz GERGES, *The war enemy, why jihad went global*, New York, Cambridge University Press, 2005, p. 194 *apud* Transnational Terrorism Security& the Rule of law: *Terrorism and the Media*, available at http://www.transnationalterrorism.eu/tekst/ publications/WP4%20Del%206.pdf, p 4.

[2] William BIERNATZK,"Terrorism and Mass Media "in *Communications Research Trends*, vol. 21, no. 2, 2002, p. 5. available http://cscc.scu.edu/trends/v21/v21_1.pdf,.accesed in 28.08.2013.

Methodologically, our approach is built on a qualitative and subjective analysis based on the content analysis instrument. The ideas and findings that will be presented below are the result of the analysis of the ten numbers of the jihadist magazine, through four indicators. The magazine was analyzed considering the *magazine sections*, the *contributors/authors* that sign articles in the magazine, in terms of *the overall tone* of the article but also the *images* presented in the journal. We will track the frequency of certain sections, the origin of the authors (political leaders/religious leaders/supporters) to determine the legitimacy of the magazine in conjunction with the objectives it sets them. Assessment records (religious/motivational instigator/objective) in which the articles are written and the analysis of images (portrait/violent images/peaceful pictures), will be an important aspect of the analysis because it will show how the editors use everything they have in their hands to generate emotions and radical behaviours.

Inspire-and inspire the believers[3]

Through Al Malahen Media foundation, the terrorist group Al Qaeda in the Arabian Peninsula succeeded since 2010, to spread online no more and no less than ten editions of Inspire magazine, turning it into a real success for the terrorist group and a veritable propaganda device for the ideals and goals of the group.

The purpose of this magazine is contained in the first page of the first editorial. The journal editors say that Inspire will be *a mean by which Muslims around the world will be brought together in the right path of Allah*; it will be an engine for *creating a more positive image for Salafi Islam* which is increasingly polluted by western media. Inspire magazine also aims to be *a platform for the most important events of the area* and an *environment of clear presentation of Islam*. By far, the most important goal proposed by the editors of the magazine is that it is meant to be a *source of inspiration for the warriors of Allah*, a catalyst for believers who have to fight in the name of Allah[4].The editors of the magazine are encouraging

[3] *Inspire-and inspires the Believers* is the motto that opens each issue of the magazine.
[4] "Letter form the editor" in *Inspire* , Issue 1 1431, 2010, p.1.

the readers to contribute with articles to this approach, offering, at the end of each edition, a series of tips and addresses where anyone can submit a contribution.

A brief analysis of the ten issues of the magazine clearly reveals the attractiveness and complexity driven not only from the interactive template but also from its interesting topics. The magazine is unquestionably an anti-American, anti-Israeli magazine and a genuine device of propaganda, indoctrination and radicalization.

The objectives of this magazine are easily identifiable in the sections and the topics that it hosts. The most common and important sections will be discussed shortly below.

As a platform for events marking the Muslim world, Inspire magazine devotes one page of each edition to the section *Hear the World ... a collection of quotes from a friend and a foe.* People that are cited in this section are divided into two categories as the title states: the "friends" and "enemies" or heroes and antiheroes. In the enemies category the most common appearances are those of the U.S. President Barack Obama, Secretary of State Hillary Clinton and former Vice President Joe Biden. Along with this, journalists and other officials of the United States security department are considered enemies. The heroes of the Muslim world are people more or less known who devote their lives to the spreading of the message of Allah. The great leaders of Al Qaeda are the most cited along with other fighters and clerics of Islam. Through this section, the magazine aims to accordingly inform the reader about major events that occurred in the Middle East region showing, in the same time, the real picture of Islam.

Another section of the magazine is the *Question we all should be asking*!. Within that section the readers have the opportunity to reflect on some questions that only have an anti American or anti-Israeli answer. The most frequently mentioned topics are related to the American presence in Iraq and Israel's position towards the Palestine situation. This section is a means by which those who stand behind it shall ensure that their perspective on important issues concerning the Muslim world is acquired in accordance with their vision.

Readers of the magazine have the chance to come in contact with the leading representatives of the Al Qaeda in the Arabian Peninsula group. Using a

shaker register the great political and religious leaders are calling Muslims from all over the world to join and fight for jihad. The same speech is maintained in other sections of the magazine like *A Call to Islam* or *The call of the Quran* in which the clerics and some religious leaders explain the basic principles of Islam. Another interesting item that is present in almost every issue of the magazine is titled *Why do I Chose Al Qaeda*. It is based on the work of Sheikh Abu Musab al Awake, a work that deals extensively with no more than 46 reasons for choosing to be part of this famous organization. During several numbers of the magazine the author discussed several reasons why you should join te Al Qaeda. Some of those reasons are:

- Because it follows the path of Jihad
- Because the organization is strong enough to survive
- Because the religion of Abraham is directed against the infidels
- Is based on universal ways to achieve victory
- Jews and Christians hate Muslims

Other sections like *My Life in Jihad*, discuss some terrorists experiences and a great source of inspiration for every reader. Almost every issue of the magazine is having a series of reflections, poems or motivational quotes.

Besides the religious, the motivational and inspirational section the magazine has a practical component that aims to prepare its readers, future Jihadist fighters, in actual fighting techniques. In this regard, *Open Source Jihad*[5] section includes a series of practical lessons, ideal for everyone who plans a terrorist attack. Open Source Jihad is designed as a handbook for those fighting against tyrants and it's considered to be "the American greatest nightmare." The Open Source Jihad section provides information about how to build a bomb (*Make a bomb in the kitchen of your mother)* about the security measures that a fighter must take, or a series of guerrilla tactics etc. The first lesson explains systematically what is the easiest way to

[5] Notice the ironic similarity with the already known Open Source Intelligence (OSINT). The editors assign the concept of open to issues concerning educating readers in the direction of acquiring skills and competencies that can be used in physical combat against the enemy. It can be seen as the magazine opened its pages not only to theoretical, ideological and motivational issues but it also has a pragmatic part where, through the technical lessons the readers can apply what they learn.

manufacture a bomb[6]. In the same section, another issue of the magazine offers a number of tips for members who live in the U. S.[7] or those who seek to destroy or burn buildings[8]. Another issue provides the leaders with the knowledge of how to produce Acetone Peroxide[9], how to wield an AK [10] or an ordinary pistol or what are the ways in which you can produce road accidents and then disappear quickly[11].

After evaluating how the content of the magazine is structured we can say that the goals proposed in the first editorial are achieved: the Jihad fighters stories are aimed to inspire and bring Muslims on the right path of Allah, the clerics' teachings promote the desired image of Islam, and the readers are provided with an x-ray accompanied by a range of perspectives on the most important events in the area.

Another indicator of the scale of analysis that we used refers to the authors of the materials present in the magazine. Based on the analysis, we have come to the conclusion that the contributors have the role to strengthen and give legitimacy to the magazine. The great leaders are not missing from the contributors list. Voices of Osama bin Laden or Ayman al-Zawahiri are heard in the first pages of the magazine. In *The way to save the earth*, Osama bin Laden, the former leader of the network, draws attention not on things that should be taken to preserve the planet, but rather the causes that gave rise to these concerns. Highly researched, the article condemns the luxury and extravagance of western countries and accuses American industry and their corporations for damaging the environment. This article opens the first edition of Inspire. Another article signed by Osama Bin Laden encourages readers to punish Americans who have done so much harm to the Muslims[12]. The interventions of the current leader of the network are also relevant.

[6] "Make a bomb in the kitchen of your mom-a detalied yet short easy to read manual on how to make a bomb using kitchen ingredients" in *Inspire*, Issue 1, Summer 1431, 2010, p. 33

[7] Tips for our brothers from United Snakes of America-from experience Yahya Ibrahim explains how to protect oneself from the enemy when conducting operation" in *Inspire*, Issue 2, Fall 1431, 2010, p. 55.

[8] Destroying buildings" in *Inspire,* Issue 3, Winter 1431, 2010, p. 39.

[9] "Makin Acetone Peroxide – Dr. Kateer has cooked up a fatal formula with ingredients widely available" in *Inspire*, Issue 6, Summer1432,2011, p. 39

[10] "Training with an AK" in *Inspire,* Issue 5, Spring 1431, 2011, p. 24.

[11] "Causing road accidents" in *Inspire*, Issue 10, Spring1432, 2013, p. 52.

[12] "In order that they taste some of what we tasted" in *Inspire* ,Issue 4, winter 1431, 2010, p. 18.

Immediately after the onset of the phenomenon known as the Arab Spring, Ayman Al Zawahiri comments on the situation and encourages the continued fight against the infidels[13].Along with this, the magazine often hosts articles by Anwar al-Awlaki, Samir Khan and other political and religious leaders of the network. The weight they give to the magazine is undeniable. Their presence not only proves the legitimacy of the magazine but also the fact that the terrorist groups are aware that the fight against infidels can be taken not only on the battlefields.

Regarding the overall tone of the magazine articles, we found that almost none of the articles can be placed in an objective register, which again demonstrates the propagandistic character of the publication. Magazine articles can be separated in two categories: motivational-instigator and religious. Below we have selected some quotes that you can easily fit in a motivational/instigator register:

> *"And fight them until there is no more Fitnah (disbelief) and the religion will all be for Allah alone"*
> *"Jihad today! Jannah tomorrow!"*[14]

In this way the readers are urged to take part in Jihad, a fight that will eliminate all unbelievers and will guarantee them a place in Paradise. All ten issues of the magazine contain messages that inspire the desire to take part in combat and otherwise bring Muslims together in this direction. These messages are subtle, hidden in the stories of the martyrs, political and religious speeches or explicit as poetry.

Deeply religious references and a language that praises Allah are also embedded into the overall tone of the articles. As a true jihadist magazine, Inspire treats the issue of death in the name of Allah gloriously and great. Each issue of the magazine treats those who resort to terrorism as heroes. Name of Allah or the Prophet Mohammed are very often invoked.

> *"Nobody who enters Paradise likes to go back to the world even if he got everything on the earth, expect a Mujahid who whises to return to the world so that he may be martyred again because of the dignity he receives from Allah!!"*[15]

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[13] "The short and long-term plans after the protests" in *Inspire,* Issue 5, Spring 1431, 2011, p. 34.
[14] *Inspire,* Issue 4, Winter 1431, 2010, p. 60.
[15] "O Martyr, you have iluminated" in *Inspire,* Issue 1, Summer 1431, 2010, p. 30.

The quote presented above shows how readers are encouraged to take actions that can bring them death, death which is the passport to Paradise. True martyrs are therefore those who would choose to leave paradise to return to earth to perform new works worthy of a martyr.

Such motivational, instigator messages motivated by deep religious reasons can convince readers to join the line of martyrs but can also generate a negative image of Islam. Even if editors do not realize the negative, violent image that they created to Islam, they promote a distorted image of Salafist Islam.

Leaving aside the content of the articles, Inspire manages to meet its objectives through the graphics and images presented in every issues of the magazine.

Portraits of leaders, clerics and enemies are present in almost every issue. The praised jihadist heroes are surprised in various poses.

The most common characters whose images appear in the magazine are Osama bin Laden, the current leader of Al Zawahiri Ayman network, the U. S. President Barack Obama and other leaders of the Muslim world (Anwar al-Awlaki etc.). Pictures of leaders like Osama bin Laden or Ayman Al Zawahiri are a catalyst and an impulse for all the Allah fighters. Put in contrast with American and Israeli enemies, portraits of Muslim leaders and clerics give legitimacy and substance to the journal content.

Violent images are also an important part of the media strategy to inspire readers to support jihadist ideals. The ten issues of the Inspire magazine are loaded with pictures of attacked places or soldiers ready to fight in a battle.

Beyond the images of brave jihadists or the damages caused by them, the editors resorted to a series of images that incite to violence.

Messages like "Yes we can" [16] to "A bullet a day keeps the infidel away[17]" encourages violent impulses while images titled "Your blood won't be wasted" ensure readers and potential martyrs that their deaths will not be in vain and that the blood which they will shed will benefit the community.

In addition to this category of images, in the magazine can be found an excellent set of explicit pictures for Open Source Jihad section. Technical

[16] Those who made this poster certainly had in mind the famous campaign slogan of President Barack Obama.
[17] *Inspire*, Issue 3, Winter 1431, 2010, p. 9.

guidance is accompanied by images that help the reader to better understand the way to build a bomb or the techniques to fight to survive.

An interesting edition of Inspire magazine is the issue of 2011 summer, issue which commemorates the death of the famous leader of the network. Killed by a Navy Seal team soldiers, Osama Bin Laden is praised and described with the most glorifying words. The day he died is considered a historic day, a day when he joined the caravan of the wise people. After a lifetime of effort, determination, patience, jihad, generosity, nobility, honesty, wisdom and tact the great leader died but his blood, his words, his spirit will standout over generations.

The importance of the nineth issue of the magazine, for our research lies in the editorial that opens the magazine. The editors are explaining very clearly that the death of the great leader does not mean the death of the magazine and that's because Allah will continue to manifest, to enlighten and inspire the lives of many members of the organization.

Through articles and the authors that the magazine hosts, the tone of the letter and the images they promote, *Inspire* is a true 'soldier' in the fight against the so-called infidels. The attractiveness of the articles and the messages that they send cannot be challenged, which is why it can be a magnet for all those who sympathize with the terrorist network. Undoubtedly Inspire can be a contributing factor in the radicalization of individuals. Beyond all this, the magazine is a success of a fundamentalist Arab media, an anti American and anti Israeli flag and a reliable partner of the Al Qaeda and terrorism of any invoice.

Aware of the potential of the magazine, the Western world has more than once took a strong position against the terrorist magazine. A U. S. official goes so far as he recognizes the quality and success of the magazine*: it is an unfortunatelly well done magazine and a virtual guide for becoming a terrorist*[18]. David Gomez, an FBI counterterrorism agent from Seattle, believes the following: *we understand the absolut serioussness of the threat from an Al Qaeda inspired magazine* and promises a number of measures to minimize or reduce the maximum possible negative effects: *assist the*

[18] "Inspire reactions" in *Inspire,* Issue 4, winter 1431, 2010, p. 11.

individuals and protect themselves from changing their behavior and making them less of a target[19].

Conclusions

Returning to the idea of Brian Jerkins, throughout the article, we have seen how the terrorist magazine of Al Qaeda in the Arabian Peninsula strengthens the idea that the media can mobilize and inspire members and also attract new supporters for the network. Starting from the goal we set earlier we conclude by stating that the editors of Inspire magazine achieve, at least partially, objectives set forth: guidance of Muslims around the world on – what they call - the right path of Allah, building what they consider to be a real and positive image for Salafi Islam, inspiring and informing readers about important events in the area etc.

Sections of the magazine as: *My Life in Jihad*, *The Call of the Quran*, *Hear the World* and *Open Source Jihad,* sprinkled with articles signed by political or clerical leaders with a large load of legitimacy (Osama Bin Laden, Ayman al Zawahiri and others), discussed in glorifying, inflammatory and anti-American registers, outlines the profile of an attractive, anti-American and anti-Israeli magazine.

Considering these issues and others that were detailed in the pages above, we consider that the journal is a genuine terrorist propaganda device that can be a perfect tool in any radicalization process. As a conclusion we can say that Inspire represents a success in the context of marriage between terrorism and the media. Using the freedom of the press and the immensity of the virtual environment, Al Qaeda in Arab Peninsula is acting in its benefit. *Inspire* magazine is undoubtedly a ”soldier” in the war against the "infidels".

Bibliograohy

1. BIERNATZK William, “Terrorism and Mass Media“ în *Communications Research Trends*, vol. 21, nr. 2, 2002, p. 5. available at http:// cscc.scu.edu/trends/v21/v21_1.pdf

[19] *Ibidem.*

2. GERGES Fawz, *The war enemy, why jihad went global*, New York, Cambridge University Press, 2005
3. *Inspire*, Issue 4, winter 1431, 2010
4. *Inspire*, Issue 1, Summer 1431, 2010.
5. *Inspire,* Issue 10, Spring 1434, 2013,
6. *Inspire*, Issue 2, Fall 1431, 2010.
7. *Inspire,* Issue 3, Winter 1431, 2010.
8. *Inspire,* Issue 5, Spring 1431, 2011.
9. *Inspire*, Issue 6, Summer 1432, 2011.
10. *Inspire,* Issue 7, Fall 1432, 2011.
11. *Inspire,* Issue 8, Fall 1432, 2011.
12. *Inspire,* Issue 9, Winter 1433, 2012.
13. Transnational Terrorism Security& the Rule of law: *Terrorism and the Media*, available at http://www.transnationalterrorism.eu/tekst/publications/WP4%20Del%206.pdf.

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The backstage of the Russian espionage activities on the Romanian territory, at the beginning of the XXth century

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Abstract

Unlike the successor Soviet regime, imperial Russia's expansionist ambitions were not global, as the Empire's only aim was to occupy the Balkans and the nearby Straits. Since 1878, Romania represented a serious obstacle in achieving these goals, which is why Russian authorities „sought to cause domestic problems" through influence, espionage and corruption of Romanian citizens.

At the beginning of the XXth century, foreign espionage represented a great challenge for the Romanian military and civilian intelligence organizations. In an attempt to implement preventive security measures in Romania, in 1908, the Department for General State Security is established within the Ministry of Interior. During Romania's neutrality period (1914-1916), this secret police force counteracted various espionage and betrayal cases.

Although most of the cases were focused on the activity of German and Austro-Hungarian intelligence services, the Department for General State Security also pursued and annihilated Czarist espionage networks.

Keywords: espionage, Russian Empire, Department for General State Security, intelligence cooperation, Ministry of Interior, Romanian Army.

Introduction

The old Kingdom becomes, through the neutrality adopted in the fall of 1914, a turning point of all the belligerents' espionage. Radu Rosetti suggestively conveys the atmosphere of an apparent eye of the storm, in the midst of a global torment, as Bucharest was perceived at the time „…the air of corruption and scheming maintained by both groups of adversaries in Bucharest, where the so called social life followed its course and the nightlife had a huge development. Beside the interlopers and usual low lives

of the capitals, as well as the more or less honest businessmen, Bucharest, and especially its hotels, cafes, restaurants were overwhelmed by an utter invasion of news correspondents, commissioners, actresses and others of the kind, some in service of one or the other power groups, others adventurers in search of financial gain"[1].

The German and Austro-Hungarian intelligence services were spending, during those years, huge amounts of money to influence the public opinion in favour of the Central Powers, having on their payrolls Romanian citizens belonging to all social strata.

While there are numerous accounts and studies regarding the economic and military espionage as well as the propaganda carried out by the Germans and Austrians, this is not the case for the espionage activity carried out on the national territory by our future ally in the first world conflagration, Czarist Russia.

The Romanian state, independent after 1878 and undertaking a strong process of modernization in the following decades represented a major impediment both in ensuring a terrestrial corridor linking the Russian Empire and the „Slav brothers" from the Balkans, and in reaching the main objective of the Empire's foreign policy – the occupation and control of the Straits. Since an open military conflict against our country was out of the question, various entities tried, through a multitude of means (the greatest majority of them coming from the arsenal of the espionage services), to create trouble for the country's governments. That happened in the context in which the Czarist Empire had superior capabilities and resources and undertook, contrary to the largely circulated opinion in the epoch, an ample process of modernization and development.

Even from its very beginnings, the Russian secret police had paid undivided attention to the espionage activities conducted in the states which presented interest for the Czarist Empire. Nevertheless, for various reasons, the results didn't live up to the expectations, the mistaken informative notes from the time of the Russian-Japanese war (1904-1905) being an edifying example in that sense. However, the intelligence and counterintelligence structures of the Russian imperial army achieved remarkable results in the first decade of the XXth century (a notable exception being the defeat in front of Japan).

[1] Radu R. Rosetti, *Mărturisiri (1914-1919*), Editura Modelism, Bucureşti, 1997, p. 62.

The military attachés accredited with the diplomatic missions, whose attributions included informative activities, proved to be extremely efficient. The Russian military attaché in Vienna, colonel Matschenko, took advantage of favourable circumstances, and was able to use to his advantage, at the beginning of the XXth century, the atmosphere and general state amongst the Austrian officers to recruit agents. Amidst many armies there are elements who will betray for any number of advantages, but the Austro-Hungarian army „excelled" in this. The list of agents recruited by the Russian officer contained intelligence officers, from the military justice, or detached in different military branches both in Vienna and the imperial provinces[2].

These, as well as others recruited by the Russian military espionage (a structure which was extremely active in Romania, too), have offered the decision makers at Petrograd the complete picture of the Austro-Hungarian adversary's capabilities, with direct effects on the unfolding of the military operations in the first year of war.

According to general Gheorghe Dabija, Romania's military attaché in Sofia during 1910-1913[3], the Russian military espionage was coordinated from Sankt Petersburg by general-major Yuri N. Danilov[4] around the onset of the world conflagration. The Empire was divided into 13 military districts, each disposing of its own agents network; the most powerful district espionage centres were, taking into account the „objectives" they had in sight, Warsaw (lead by colonel Nikolai Batiushin, the one who had managed to recruit the head of the Austro-Hungarian military counterespionage, colonel Alfred Redl), Odessa (from where, as we will see along the study, the espionage directed against Romania was conducted) and Kiev.

From his official stance, general Dabija wrote, referring to the collaboration he had in Sofia with the Russian military attaché: „colonel Romanowski, intelligent, with a moderate and sensible spirit, with very distinguished manners, a gentleman. An excellent Major State officer, I have had the best rapport with him, working close together, which was notable, *since he had extensive informative means and possibilities, which I completely lacked.* Nevertheless, thanks to the friendship that bound us, both I and my country have benefited."[5]

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[2] Alexandru Popescu, *Agenţii mărturisiţi. Diplomaţii şi spionajul*, Editura Cetatea de Scaun, Bucureşti, 2009, p. 72.
[3] Gheorghe Dabija, *Amintirile unui ataşat militar român în Bulgaria. 1910-1913*, Editura Ziarului „Universul", Bucureşti, 1936.
[4] Leonard Raymond, *Secret Soldiers of the Revolution*, Greenwoodpress, 1999.
[5] Gheorghe Dabija, *op. cit*., p.54.

Although it is still not a fully elucidated subject, we can also talk about a certain foreign involvement where the onset and unfolding of the peasant revolt from 1907 is concerned, an event with major reverberations on the national public opinion.

In connection with this issue, the first report addressed to the state leadership at the beginning of the uprising by Jules Văsescu, the prefect of Botosani county, demands, on the 10th of March 1907, that the troops sent as reinforcement be cavalry, as the instigators do not come from the revolted villages, but are rapidly moving from village to village: „*they are emissaries who roam the villages and promise, in the name of His Majesty the Emperor of Russia, to distribute the land to peasants, and encourages them to revolt, so that Russia will come to power in this country, since only they will be able to distribute the land"*[6].

In the second report of the prefect, dated 11 March 1907, the army's help request is renewed, because the situation was rapidly worsening: „The revolution phase has changed, the inhabitants, thanks to the instigators – *believed to be Russians by nationality* – who roam the villages, seeing that they were able to determine the landlords to fulfil their demands, ask for more: to divide the lands among themselves… There is an absolute necessity for cavalry, in order to successfully pursue the gangs that roam the villages in order to determine the uprising of the peasants. The infantry cannot carry out this mission."[7]

Although during the following decades the existence of these Russian, instigators or paid by the Russians, was denied, it is obvious that Petrograd was trying to take full advantage of any internal problem Romania might have had, fact which was all too well known by the Romanian governors. This is why, starting with the 7th of March, the Romanian authorities ordered that the borders close „from Suceava to Mihăileni" so as to prevent the infiltration of agents dressed up as peasants from Bucovina and not to provide a pretext for military intervention on the part of Czarist Russia and Austro-Hungary[8].

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[6] *Răscoala din 1907*, vol. I, Editura de Stat, Bucureşti, 1948, p. 49, *apud* Alex Mihai Stoenescu, *Istoria loviturilor de stat în România*, vol. 2, Editura RAO, Bucureşti, 2001, p. 134.
[7] *Ibidem*, p. 54 (Raportul nr. 1933 din 11 martie 1907), *apud* Alex Mihai Stoenescu, *op. cit.*, pp. 134-135.
[8] Alex Mihai Stoenescu, *op. cit.*, p. 131.

Unfortunately, the files of the Police Department and the Department of General State Security that can be found at the Romanian National Archives (RNA) do not shed any light with regard to this matter, so that a definite conclusion might be reached. The researchers have yet to complete, in different archives from Bucharest or the rest of the territory, a laborious work of clarification concerning several aspects of Romania's modern history.

Nevertheless, the documentary basis at the RNA allows us to reconstitute one of the Russian espionage networks from Romania, at the beginning of the XXth century, painstakingly structured over many years. Since many of the files belonging to the huge operative archive of the State Security have disappeared, or have been destroyed during the past century, we don't have a complete image of the phenomenon, but "pieces of the puzzle". Because of this, we cannot make a definite statement in connection with the undoubted and obvious guilt of all the persons mentioned in the documents which were written by the agents and informants of the Police and State Security.

The espionage of the Czarist Empire on the national territory up to Romania's entrance in the First World War

The law reorganizing the Ministry of Interior adopted during the mandate of Secretary Vasile Lascăr, April 1903, was intended to be the answer to the evolution of society at the beginning of that century; but the events that followed showed that this was appropriate for the institution of Police only as „administrative police", lacking the intelligence component, the one which meant collecting the information[9].

The peasant uprising from March 1907 played the role of a real „cold shower" for the Romanian political elite, who were totally taken aback because they lacked pertinent information on the explosive situation registered at that point in the rural world. This is why, in March 1908 a law is adopted, by which the Department of Police and General Security (DPGS) is established, consisting of two sections: the General State Security and the Police. To ensure an increased efficiency, all the structures having state security attributions were organized and functioned separately from the General State Police, being much less exposed to the pressures coming on the part of the local authorities, like the prefect or the political parties[10].

[9] Adrian Pohrib, *Din istoria Poliţiei Române. Poliţia oraşului Galaţi între anii 1832 şi 1949. Istoric şi documente*, Editura AGATON, Galaţi, 2013, p. 63.
[10] Alin Spânu, *Serviciul de informaţii al României în războiul de întregire naţională (1916-1920)*, Editura Militară, Bucureşti, 2012, p. 27.

Looking to create a strong state institution with special assignments, the leadership of the state saw in the General State Security the „nerve of Police which is duly tensed by the environment, conducting to the general measures in matters of public order and state security, registering at the same time all the seismic activity occurring in domestic population as well as in the neighbouring countries, so that it may prevent, in due time, those subversive moves against the security of the state"[11].

A significant amount of attention was also paid to the Police from the border crossing points and harbours, which was under the direct leadership of the Secretary of Interior and was exercised by the director of DPGS, who had the right of complete control over the entire activity[12].

In conclusion, the State Security, as the main institution with attributions in collecting information both internally and externally, had the duty to ensure constitutional order, the country's internal security and to counter the actions carried out by hostile states, which would have attempted to endanger Romania's independence and territorial integrity.

Due to the close collaboration between the different structures of the power institutions belonging to the state (especially the Ministry of Interior and the Army) many of the attempts by different foreign powers to find out about Romania's strengths and vulnerabilities were discovered and annihilated. Some successful examples are presented in the following lines.

One of the intensely mediated espionage cases in the epoch, in which the Czarist espionage was definitely involved, is that of the artillery captain Rodrig Goliescu. A talented inventor in the field of aviation at the beginning of the XXth century, as well as a person with doubtful morals, eager to become rich and living over the means offered by his military condition, he enters a dangerous game of national treason[13].

Sent with substantial financing from the Romanian state to Paris, in order to perfect his invention (the „avioplane" – a hybrid airplane), he returns in the autumn of 1910 with unpaid debts. In Bucharest, taking advantage of the fictitious company that he had registered in France – „The society of aviation Goliescu et comp", he tries, without too much success, to scam people who were willing to invest in a flourishing business. On the occasion of his visit to Russia, made in order to get the approval for

[11] Vasile Bobocescu, *Istoria Poliţiei Române*, Editura Ministerului de Interne, Bucureşti, 2000, p. 141.
[12] Adrian Pohrib, *op. cit.*, p. 64.
[13] See C. Neagu, D. Marinescu, R. Georgescu, *Fapte din umbră*, vol. II, Editura Politică, Bucureşti, 1977, pp. 49-57.

his avioplane inventor's certificate, from the Ministry of Industry, he enters the attention of the Russian espionage. In June 1912 he is contacted by the Russian agent Piotr Altinovici, interpreter at the Russian Legation, who recruits him as informer.

In a note discovered when searching his house, Rodrig Goliescu assumed, in writing, the obligation to transmit the Russian intelligence service a number of documents with regard to the national security: the mobilization plan of an infantry regiment, with all the necessary data; the last edition of the Mobilization regulation and the concentration plan of the Romanian army in case of war with the Czarist Empire or Austro-Hungary; the Major State's plan of military transports on the railroads in case of mobilization, etc.[14].

The need to procure the necessary military information makes him look for help, which is fatal. His former subordinate, M. Predescu, whom he had contacted in order to steal the documents form the Great Major State, presented the case to his superiors, which meant that Goliescu was taken over by the General State Security, which had the required competencies and resources to monitor him. He will be arrested on the 13th of February 1913, with the news spreading like wildfire all over the capital.

Because of the given situation, Piotr Altinovici clandestinely leaves the country, avoiding the monitoring performed by the Romanian agents; in the document issued as a consequence of searching his house, the police officer appointed to execute the mandate of bringing him states that „he is out of the country and there is no information related to his whereabouts"[15].

In the spring of 1913, the War Council of the II Army Echelon started the instrumentation of the process. The sentence from the 22nd of June 1913 condemned captain Goliescu to twenty years of hard labour and military degradation for „high treason and forgery of signatures and seals"[16]. He outlives the war, being set free in 1925, but all his latter attempts to officially rehabilitate himself were doomed (he dies in 1942).

The Russian-Bulgarian collaboration aimed at spying the Romanian military apparatus

In a very important Report dated November 12th 1907, submitted to the Home Secretary and to the War Secretary also, the DPGS Director draws attention upon a dangerous case of espionage in which Bulgaria was involved and most likely Czarist Russia, too. Thanks to the efficient collaboration

[14] Paul Ştefănescu, *Istoria serviciilor secrete române*, Editura ANTET, Prahova, 2007, p. 36.
[15] *Ibidem*, p. 55.
[16] *Ibidem*, p 56.

between institutions in matters concerning national security, the Postal Office from Odobesti sends the Department of Post and Telegraph a parcel considered suspicious, which is then sent to the General State Security. Here it is opened and closely examined, only to conclude that it is a case which can seriously affect Romania's security. The parcel was addressed to a Bulgarian artillery officer who lived in Sofia, lieutenant G. Hesapcieff and contained maps and detailed military plans of a part of Moldova.

Director Panaitescu highlights, among other things, the existing cooperation between the Russian and Bulgarian institutions, having as a joint objective the espionage of our country. This was vital for the Czarist army and espionage service because any arrival in our country of a Russian employee, civilian or military, was rigorously registered and monitored both by the Police and Security or County Police. However, the movement freedom of the Bulgarian citizens was much greater on Romanian territory.

„The logical conclusion would be that this espionage was carried out in the best interest of the Bulgarian army. Nevertheless, since the area represented by the afore mentioned maps is situated beyond the fortified line Focşani Nămoloasa, (Putna-Bacău), a region which falls outside the Bulgarian interest zone, it is not excluded that this espionage activity is performed by the Bulgarians to serve Russian interests. It is possible that Russians use Bulgarian undercover officers, since it is much easier for them to enter the country without being noticed, mingling with Bulgarian workers and merchants who can be found at the gates of all our military establishments.

There is not one troop who starts its march without being followed by the Bulgarian merchants everywhere, only God knows how many of them are undercover officers. It would have been very difficult for Russian officers to enter the country and mix with the population, they would have been immediately discovered, since they could have only dressed up as icon painters, which are always suspects for the authorities and even if they had not been discovered, they would still not have been able to do a very good job, not having the possibility to stay around military units and travel along with the troops in marches, exercises and manoeuvres..."[17].

In conclusion, the report of the General Director of DPGS draws attention on the necessity that „The Grand Major State of the Army establishes a counter-espionage service, which should be well organized in order to easily reveal the spies who roam the country". All the more since „the Bulgarians are up to date with everything that our marine and army

[17] Romanian National Archives (RNA), The *General Police Department* Fund, File no. 94/1907, sheets 19-20.

do and plan, and they arrive on time to spy on them and get information on the matters that are of interest to them"[18].

Due to this we must also show the ability of the DPGS to carry out external espionage actions. Due to the special importance given to the case, an experimented agent of the General Security, Grigore Radulescu, is sent to Sofia, in Bulgaria, in order to obtain more details related to the receiver of the parcel, the Bulgarian artillery lieutenant Hesapcieff. On this occasion Iancu Panaitescu assigns Radulescu to also obtain information on „a certain Mincoff, merchant and cards player, who sometimes comes to Romania and carries out espionage missions, as far as I am informed"[19]. In order not to look suspicious to the Bulgarian counter-espionage, he will be accompanied by his wife, who will contribute to the informative monitoring of the Bulgarian officer.

The Romanian agent-couple permanently monitors the lieutenant, establishing that he works at the „Army arsenal in Sofia, in the chemistry laboratory which prepared the explosive material for cannonballs". They characterized him as being an especially scrupulous person, serious and very well seen by the Bulgarian officers with whom he had interacted, on different occasions, in town"[20].

Of great importance for the prevention of actions which could have affected the national security and internal order proved to be, on the 31st of March 1904, the adoption of the Regulation of the police and frontier, railways and harbours activities, through which the Frontier, Railways and Harbours Police is organized. It had the main mission of preventing the entrance of anarchist activists on national territory and annihilating the foreign services' actions against Romania, by signalling to the General Security any possibly dangerous foreigner.

Mention must be made of the fact that the document made an exception for the arrivals/departures of the Romanian citizens from Austro-Hungarian and Czarist Russia. With this action Romanian refugees, who were pursued by the repressive Austro-Hungarian and Russian organs for participating in the national emancipation movement, were protected[21].

From the notes and reports of the security or police agents up to the onset of the First World War, found in the archives, it can be seen that there was good collaboration between this frontier police with large prerogatives

[18] *Ibidem*, sheet 21.
[19] *Ibidem*, sheet 30.
[20] *Ibidem*, sheets 22-24.
[21] Vasile Bobocescu, *Momente din istoria Ministerului de Interne*, Editura MI, Bucureşti, 2000, vol. I, pp. 82-84.

and the Department of Police and General State Security, a structure which officially came to life in March 1908.

Actions of the Czarist military espionage on the national territory
Case study – Vladimir Nicolaevici

A unique document, found in the Central National History Archives, shows an important part of the Russian military espionage network in Romania, presented by the very person who was considered a trustworthy spy, the lawyer Vasile Alexandrescu, from Iaşi. He had denounced to the General State Security the Czarist service's secret operation, presenting the Romanian citizens who were willing to procure, in exchange of particular amount of money, the information solicited by the Russian party.

With regard to this subject, the central „character" is the Russian citizen Vladimir Nicolaevici, considered a well-versed spy by the security, a specialist in the east European space, who often travelled to Bulgaria and Serbia. Practically, during 1914, due to the onset of the world war, the intelligence necessities grow exponentially, for all the belligerents who need information related to their declared enemies as well as neuter states like Italy or Romania.

In the Paper written by the deputy director Stan N. Emanuel and presented to the board of the DPGS on March the 2nd 1914[22], it is shown that:„A part of the Russian military espionage in Romania is the espionage service organized especially for Moldova, with its central headquarters in Odessa, at the Russian Major Sate, the Odessa military circumscription …The connection between Odessa and Iaşi is made by a certain Vladimir Nicolaevici, of Russian origin, a fake merchant, who was traveling to Romania very often and has been suspected of espionage for a long time.

From the examination of File no. 227, from the secret archive of the Department, it appears that this Vladimir Nicolaevici addressed lawyer Alexandrescu from Iaşi, suggesting that in exchange of a sum of money which he will receive monthly, he should take interest in the activity of these agents, and their Reports should be sent to Odessa.

Lawyer Alexandrescu denounced everything to the Department and since we were interested in knowing the military interest points of the

[22] Romanian National Archives (RNA), The *General Police Department* Fund, File no. 1/1914, sheets 30-33.

Russians, as well as knowing who the persons doing this type of services to the Russians were, we requested that lawyer Alexandrescu accept the proposition.

Accepting he was immediately acquainted with the agents from all over the country, respectively: Vasile Gavrilescu, belt-maker established in Roman; Mihai Pălimaru, singer, retired sergeant in Bat. 8 Hunters, established in Husi; Mihail Christescu, the representative of the village federal cooperatives from Bucharest, living in Brăila.

The correspondence which is circulated between the recruited agents with lawyer Alexandrescu and between the latter and Vladimir Nicolaevici from Odessa is written by the known Russian procedure, namely by using chemical substances and revealing the writing with other substances."

The urgency of the military information required by the imperial army and the (premeditated or contextual) delays with which Alexandrescu answered the requests of the Odessa headquarters, determine Vladimir Nicolaevici to enter the national territory on July 3rd 1913, accompanied by another „Russian subject", Zeilich Champanier. Nicolaevici started a tour through Romania, starting in Iaşi, followed by Galaţi, Bucharest, Constanţa, heading back to Russia on the 2nd of August 1913.

Important information for the DPGS board is transmitted by the same lawyer, who became a very valuable agent for the Romanian counterintelligence structures and was, ironically enough, appreciated by our adversaries as well. As a proof of confidence which he had gained with the Russian spy, Nicolaevici presents him with all the novelties, after returning from Iaşi and before going back to Russia: in Galaţi he had „four civilian informants with good material situations and extended military knowledge", in Constanţa he had hired yet another agent (from which we deduce that here he had already established an active espionage network). Although he did not communicate the name of these new „acquisitions" to the Romanian lawyer, he drops a very important detail for the Security, particularly that „the transmission of the written information from the counties neighboring Russia is made through some of our customs officers (Romanians)"[23].

[23] *Ibidem*, sheet 31. It could not be precisely established if this information transfer was possible due to our officers' corruption or the inventiveness of the Russian couriers.

Here is the type of information requested by the Russian military espionage, as it appears from the letters sent throughout September 1913 by Vladimir Nicolaevici to Alexandrescu:

„1. How the infantry, artillery, reserve units were organized during the mobilization.

2. How the troops transport was made on the railroads: in how many trains an infantry, artillery, cavalry regiment was transported.

3. How many reserve regiments were mobilized and their registration number.

4. Idem for artillery.

5. If it was possible for the Division no. 11 to be created at Dobrici and Division no. 12 at Mangalia"[24].

The urgency to collect military information determines Nicolaevici to return to Romania on the 25th of November 1913 (he will stay until the 23rd of December 1913) and then on the 12th of January 1914; practically, during 1914 he stays on our national territory for long periods of time, being constantly monitored by Security agents. The surveillance is carried out constantly, being registered on hundreds of report pages, each meeting, each move of the Russian citizen being supervised, to its most minute details.

One aspect becomes obvious from the surveillance of Nicolaevici, as well as the other „Russian subjects" suspected of being spies, and that is, the complex network created on Romanian territory throughout the past decades. In the capital, the Russian Consulate and the Russian Church were headquarters of these activities, for the Romanian agents mention that Nicolaevici frequently visited the Russian Consulate, and the Bailiff of this Consulate, Petre Terzici, had the mission of sending to Nicolaevici the correspondence sent by the Russian Major State from Odessa (according to a note that entered the Security's possession).

„He almost permanently contacted many of those who were suspected by the Department for espionage, namely: Alexe Drosdov and Vorocilov from the Russian Chapel, priest Politoff from the Russian Church, merchant Teodor Godezlinschi, Russian captain Anatol Troitzki, the Russian military attaché etc…"[25].

Security's agents register each of his journeys, including the states of mind through which the Russian spy goes through, as follows: „mention should be made of him awaiting with nervous gestures in different parts of the capital, as well as his stationing twice in front of the Artillery school, where he seemed to have been waiting for someone.

[24] *Ibidem*, sheets 31-31v.
[25] *Ibidem*, sheet 35v.

Among meetings which take place in the street and particular places, involving women of Russian nationality, a certain Nadia could be identified, who is also under surveillance and on which information is received."[26]. His activity is prolific, taking part almost daily in diverse meetings which are more or less conspired.

The thoroughness with which he promotes his legal status denotes a character with experience in espionage activities, the Security having observed that he is very careful that his official cover of Russian businessman remains credible. Therefore, he makes sure that he is always in possession of some catalogues with the industrial products of several Russian companies, as well as „papers with the visa of the Romanian consulate from Odessa, according to which he is a voyaging interpreter".

In the end, as a conclusion, the Paper suggests that „this dangerous Russian military spy" be banished from Romania through a decision taken by DPGS. However, because of the interest shown by the intelligence structures in knowing about his connections in Romania, the decision was postponed indefinitely. Therefore his stay is allowed, but only under careful surveillance. His meeting with the already mentioned characters continue in Bucharest, especially with the Russian captain Anatol Troitzky and the priest Politoff from the Russian church (whom he also visits at home).

The importance given by the State Security to this espionage network also derives from the order given by the DPGS Director, Iancu Panaitescu, to receive personal reports containing the information resulting from Mihail Christescu's surveillance, the representative of the village cooperatives' federal from Bucharest.

A very interesting aspect, known by the national intelligence structures, was the exchange of secret letters between the Russian spy and lawyer Alexandrescu from Iasi, in May 1914. The Russian soldiers from Odessa were very upset by the lack of valuable information delivered by the Romanians (these were elaborated under the supervision of the General State Security); Nicolaevici was very explicit on this aspect: "Your latest letters only contain general political information…which we cannot make use of…..What we do need is military intelligence…You have to urgently make the acquaintance of soldiers from troops established in Iasi, so that you can find out about the regiment's lifestyle and write all about it to us……You must provide us with all the information on the Romanian army…on the change of the army's organization and on the formation of new units…..on the navy, cannons' orders, clothing, guns, projectiles[27]."

[26] *Ibidem*, sheet 32.
[27] *Ibidem*, sheets 97-97v.

It was asked of him that this information be as detailed as possible, the Russian espionage being interested even by the possible financial offences registered at Romanian units, names of the officers who had received disciplinary penalties, incidents among officers, etc. It should be reminded that this type of „sensitive" information (focused on the officer's daily life) lead to the recruitment of the Austrian colonel Alfred Redl in the beginning of the XXth century (a particular success of the Russian intelligence officers) with catastrophic aftermaths for the Austro-Hungarian monarchy during the world conflagration.

In the second letter sent during the same month, lawyer Alexandrescu receives an ultimatum from the Russian military espionage: „You communicated to us that there is nothing new with regard to the army. That is a lie, now there is talk in Romania of establishing new units, orders have been made for the navy. A new 11th division will be established and you haven't written anything about it. Very bad. If you intend to write in invisible ink, write on the new address instead of the old one: Russia – Odessa – Piskenovskaia No.19 loc. 4 Palaghee Dumitrieve Volodinoi…..If you should sent information without military content, we shall spare your services"[28].

It is obvious that the Russian spies disposed of functional networks in Romania, since they knew about the changes which had come up in the national military apparatus and they could not be fooled too easily. We can get an image of the relations the Russian „businessmen" in the Romanian society by tracking Vladimir Nicolaevici's acquaintances in Bucharest, which contained militaries and civilians with particular social statuses.

He is seen in the company of many Romanian citizens, on some of whom there is further information. The surveillance team reports that on the 25th of May 1914, Nicolaevici meets two Romanian citizens at Café Bristol, one of them was an artillery lieutenant, identified as Vintilă Popescu, belonging to the Piteşti garrison.

The supervision of Vladimir Nicolaevici's activity in Bucharest between May and August 1914 meant an important logistical effort on the part of the institution's employees, because of the fact that the persons he interacted with, had to be, in turn, supervised.

We will take, for example, Ludvig Copici, the hairdresser and administrator of a hair salon on Calea Victoriei, who was already suspected by the General Security of carrying out espionage actions for Petersburg. His behaviour had attracted the attention of the agents because „in the morning, at 7, when he exits the courtyard he takes a few minutes to observe

[28] *Ibidem*, sheets 105-105v.

the street, and only then does he leave for work, then at every crossroad he stops and checks whether he is being followed…."[29].

Agent no. 8 from the 1st Brigade of the State Security, which had the building (where the salon was) under surveillance, reports on the 10th of July 1914 that during the previous day, around 18 o'clock, Copici's wife went out of the beauty parlor and entered the Russian Imperial Consulate on Calea Victoriei, going up the stairs „to the right side apartment, where the Consul's Chancellery was, as I found out, and she remained there until 7 o'clock when her husband also went up, only to come back to the parlour fifteen minutes later……

From the conversations I had with Mr. Costescu, a hatter who lives next to the Russian Legation, I found out by indirect and discrete questions that the Copicis were at the reception organized on the occasion of Mr. Fasanov's visit (the Russian Secretary), in June, this year. *The couple are known as devotees of the Russian Consul, often visiting him in his very apartments, not only in the Chancellery*"[30].

Taking into account the social and diplomatic status of the Consul his friendship to a hairdresser and his wife is suspicious (even if they manage the respective location). This aspect was also suggested by the Security's agents during the monitoring. Unfortunately, the notes and reports presented in the pages of the files from the Central Historical National Archives do not shed further light on this issue.

His „work" relations also extend to the army, as he frequently contacted an artillery officer during July 1914. The officer is lieutenant Ionescu, the son of a Romanian general in the army, according to an informant of the Security. The information will be transmitted to the leadership of the army, in particular general Dumitru Iliescu, the actual leader of the Great Major State.

The meetings take place at café Boulevard, in the centre of the capital, in the evenings, where the lieutenant goes to the table which is already occupied by the Russian. After having a couple of beers, the Romanian officer would accompany him home, where he would stay for at most an hour, heading back to his house afterwards. The close supervision of the Russian citizen was not able to provide details based on which we could draw a conclusion referring to a possible delivery of the Romanian army's secret documents or information to the Czarist espionage[31].

Where Vladimr Nicolaevici is concerned, by the Galaţi Security Brigade's note, from the 6th of August 1914, the DPGS board is informed that he had left the country: „…..Today, the 6th of August, 8 a.m. he left the hotel,

[29] *Ibidem*, sheets 166-166v.
[30] *Ibidem*, sheets 171-171 v.
[31] *Ibidem*, sheets 172-198v.

went to the Russian Agency and embarked on the Russian ship to Odessa. He was accompanied by the Russian journalist Ilios Gorelik….Nothing suspicious could be noticed as a result of V. Nicolaevici's monitoring"[32].

Although the name of the Russian spy is not found in the reports of other GSS agents, there are many Russian citizens suspected of collecting both civilian and military information, which was necessary to the Czarist military to create a realistic picture of what Romania represented at that time, especially in the perspective of our engagement in the world war.

Conclusions

After being close to fulfilling their geopolitical goal of controlling the Straits[33], in 1878, Czarist Russia's politics towards Romania was constant and categorical during the next few decades; its objectives were to undermine and create, as much as possible, social and political unrest, to show „the civilized world" that the Romanian state was not viable and, consequently, did not deserve to exist inside the borders which the European powers had acknowledged.

Czarist Russia's espionage activity on Romanian territory was complex and focused on obtaining detailed knowledge concerning key political and economical aspects, as well as on the „informative control" of important political figures, organizing attempts on the lives of those who were uncomfortable for the imperial politics in the region.

A notable fact is that the secret agents' network was heavily supported by elements belonging to the strong Slav minority, which had already been established on our territory for generations. Moreover, after Romania was consolidated as a state, a large number of „Russian subjects" were registered in our country, looking for a better life.

As an example of direct intervention on the part of the Empire's representatives in the Romanian socio-political life during the latter decades of the XIXth century, we shall present the United Opposition's moment, which intended to overthrow, after violent upheaval, the liberal government lead by Ion C. Bratianu (March 1888).

The reputed journalist and politician, Constantin Bacalbasa, an eyewitness to the events, has left an eloquent testimony to this effect: „The Russians were not even worried about being discovered; the Russian legation's agents were present everywhere on the occasion of the street

[32] *Ibidem*, sheet 199.

[33] The Russian troops had reached the capital of the Ottoman Empire, it was only the categorical opposition of England and the new European power, Germany, that prevented the Czarist Empire from breaking the balance of power at a continental level.

protests of the past few days. On the 15th of March the entire Russian legation, except the Secretary, was on Dealul Mitropoliei. The legation secretary, Lermontoff, stood so close to the fighters that he felt cartridge dust on his cheek"[34].

Beyond the expected confrontation between the Romanian and Czarist intelligence structures, we should take into account the existence of a certain degree of cooperation, during 1915-1916, given the public opinion's preference for Antanta. Subsequently, certain German-Austrian attempts to disrupt, on Romania's territory, the Serbian ammunition supply from its ally, Russia are annihilated[35].

Romania's entrance into the World War, in August 1916, transformed the Czarist Empire into an official ally, with whom we were supposed to have, at least officially, a close military and political cooperation. Nevertheless, this was not put into practice as it should have been, being one of the causes of the military disasters suffered by the Romanian army in the 1916 campaign. The modernization and transformation process undergone by the Romanian army in the winter of 1916/1917 materialized in a solid collaboration with the equivalent Russian intelligence structures.

The onset of the Bolshevik revolution in October 1917 is followed by a period of restlessness which puts the relationships between the two allies on strain. Russia's exit from the war in December 1917 and the attempts to implement communism in Moldova, which was left under the control of the Romanian government (the winter of 1917) culminate with the breach of the diplomatic relations (January 1918) and the establishment of a very dangerous conflict for the new Romanian state, as Basarabia represented the great inter-state issue in the period between the two World Wars.

During the next few years the espionage structures of the Soviets (CEKA and later NKVD, as well as the military espionage – GRU) will try, using all the available means, to create social unrest and convulsions in Romania, which was considered an „imperialist state". The confrontation will become a bloody and brutal one, the Secret Intelligence Service – SIS and 2nd Department of the Great Major State of the Romanian Army will stand out through their professionalism and the sacrifice spirit of the agents, civilians and militaries involved, many of whom paid with their lives for the intelligence collected from the Soviet Union Moreover, after 1945 a heinous repression commanded by Kremlin unleashes over all of those who had handled the „communist issue" as functionaries of the intelligence structures.

[34] Constantin Bacalbaşa, *Bucureştii de altădată*, vol. III, Editura Albatros, Bucureşti, 2000, p. 124.
[35] Romanian National Archives (RNA), *The Department for General State Security* Fund, File nr. 177/1914, sheets 1-10.

Bibliography

1. Romanian National Archives, *The General Police Department* and *Department for General State Security* Funds.

2. Bacalbaşa Constantin, *Bucureştii de altădată*, vol. III, Editura Albatros, Bucureşti, 2000.

3. Bobocescu Vasile, *Momente din istoria Ministerului de Interne*, vol. I, Editura Ministerului de Interne, Bucureşti.

4. Bobocescu Vasile, *Istoria Poliţiei Române*, Editura Ministerului de Interne, Bucureşti, 2000.

5. Dabija Gheorghe, *Amintirile unui ataşat militar român în Bulgaria. 1910-1913*, Editura Ziarului „Universul", Bucureşti, 1936.

6. Neagu C., D. Marinescu, R. Georgescu, *Fapte din umbră*, vol. II, Editura Politică, Bucureşti, 1977.

7. Pohrib Adrian, *Din istoria Poliţiei Române. Poliţia oraşului Galaţi între anii 1832 şi 1949. Istoric şi documente*, Editura AGATON, Galaţi, 2013.

8. Popescu Alexandru, *Agenţii mărturisiţi. Diplomaţii şi spionajul*, Editura Cetatea de Scaun, Bucureşti, 2009.

9. Raymond Leonard, *Secret Soldiers of the Revolution*, Greenwoodpress, 1999.

10. Rosetti R. Radu, *Mărturisiri (1914-1919*), Editura Modelism, Bucureşti, 1997.

11. Spânu Alin, *Serviciul de informaţii al României în războiul de întregire naţională (1916-1920)*, Editura Militară, Bucureşti, 2012.

12. Stoenescu Alex Mihai, *Istoria loviturilor de stat în România*, vol. 2, Editura RAO, Bucureşti, 2001.

13. Ştefănescu Paul, *Istoria serviciilor secrete române*, Editura ANTET, Prahova, 2007.

14. Troncotă Cristian, *România şi frontul secret*, Editura ELION, Bucureşti, 2008.

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sensors

MDPI

Article

IoT Based Heart Activity Monitoring Using Inductive Sensors

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Abstract: This paper presents a system dedicated to monitoring the heart activity parameters using Electrocardiography (ECG) mobile devices and a Wearable Heart Monitoring Inductive Sensor (WHMIS) that represents a new method and device, developed by us as an experimental model, used to assess the mechanical activity of the hearth using inductive sensors that are inserted in the fabric of the clothes. Only one inductive sensor is incorporated in the clothes in front of the apex area and it is able to assess the cardiorespiratory activity while in the prior of the art are presented methods that predict sensors arrays which are distributed in more places of the body. The parameters that are assessed are heart data-rate and respiration. The results are considered preliminary in order to prove the feasibility of this method. The main goal of the study is to extract the respiration and the data-rate parameters from the same output signal generated by the inductance-to-number convertor using a proper algorithm. The conceived device is meant to be part of the "wear and forget" equipment dedicated to monitoring the vital signs continuously.

Keywords: IoT; UH; inductive sensor; textile-based sensor; heart rate sensing; respiration sensing; inductive to number convertor

1. Introduction

Nowadays, the Internet of Things (IoT) through which a network of smart objects work together in collecting and analyzing big collections of data and autonomously perform actions is becoming real, thanks to the machine-to-machine (M2M) technology [1]. Globally, M2M connections will grow nearly threefold, from 4.9 billion in 2015 to 12.2 billion by 2020, accounting for nearly half (46%) of all connected devices, including medical devices. "For 2020, the installed base of Internet of Things devices is forecast to grow to almost 31 billion worldwide [1]". The medical area will grow fivefold, the fastest, from 144 million connections in 2015 to 729 million in 2020 [1]. There are many applications of IoT in medicine, including in electrocardiography [2–17].

Chronic disease management is important for the self-management of health and the IoT concept plays a significant role. Personal medical devices need two features: Applications that use network protocols and intelligent services to achieve them. However, most have only one function: To indicate data and save them temporarily. This paper suggests a smart health service model that gives a concrete response to an individual. To do this, we have introduced a collaborative protocol that transfers risk factors between IoT and personal medical devices. "Ubiquitous Health" (UH) is a model where

individual medical data were measured by ubiquitous (UHD) personal medical devices, then sent to a dedicated server to provide answers to medical staff and patients. The intelligent clothes represent a paradigm that gains a large area in people's life. The technological progress determines an easy implementation of models in wearable devices, the "wearability" being a needed feature of intelligent clothes [17–28].

"Smart textiles are defined as textile products, such as fibers, filaments, and yarns together with woven, knitted or non-woven structures, which can interact with the environment/user" [21]. This interaction implies changes in certain values of electric or electromagnetic fields modifying the values of physical parameters such as resistances, capacitances, and inductances.

We can talk about capacitive smart textiles by applying conductive paint on a fabric in a configuration of capacitor electrodes [22–24], the capacitances values being determined by a relative position of an object related to the surface of the electrodes. The smart textile concepts imply two directions of development: Implementing of passive components like resistors (by conductive tissues), inductances (by coil shape), and capacitive, but also, we should take into account the possibility to implement active components like transistors. In this case, we can imagine a configuration of the circuits distributed on the surface and in the volume of the clothes.

A capacitive sensorial structure was conceived in order to detect the roll-pitch-yaw rotations of the neck and hands. The capacitive sensor was positioned on the collar and on the sleeves of the clothes and an accelerometric sensor was dedicated to determining the neck and trunk movements.

The accelerometric sensor is placed on the collar, in the cervical zone, close to the capacitive sensors [24]. An inductive proximity sensor is dedicated to monitoring the mechanical heart activity by inserting a planar inductive sensor in the fabric of the clothes in front of the apex zone. The displacements of the chest tissues during systole and diastole phases are seen as inductive changing values that are converted into digital numbers.

The paper presents an ECG (Electrocardiography)-based monitoring system [23] using an acquisition device of the ECG signals to which electrodes are attached using wires that will be in contact with the patient's skin (over the sampling period) and also an accelerometer device.

This system supports the following functions: ECG signal acquisition, heart rate monitor, respiration rate measurement based on impedance pneumography (see Figure 1). The device dedicated to monitoring the heart activity consists of a planar inductive sensor that is inserted in the fabric and is connected to a LDC circuit (Inductive to digital convertor), of a microcontroller that gathers the inductive data and sends them by an RF module to a server. One inductive sensor only is incorporated in the clothes in front of the apex area and it is able to assess the cardiorespiratory activity while in the prior of the art are presented methods that predict sensors arrays which are distributed in more places of the body.

The heart activity monitoring using wearable biosensors has as a goal the continuous assessment of cardiovascular parameters [23–25]. An advanced photoplethysmographic technique is presented in [25].

This technique adopts as a monitoring device a ring that incorporates a sensorial structure which is able to measure the heart parameters such as heart rate, oxygen saturation, and heart rate variability. "Wearable electrocardiogram systems represent the most mature WBS technology." [27].

The same devices are used in order to store ECG signals for a determined time period being able to generate outputs for heart rate and respiration. Dedicated integrated circuits with these functionalities have been developed (we would like to mention here ADAS1000 from Analog Devices).

The movements of the tissues are detected by acceleration sensors which could be used in order to identify and to reduce the motion artifacts [28].

A planar inductive sensing element ("flat spiral") which is inserted in the clothes in order to detect the vital parameters (heart-rate and respiration) is presented in [29]. The simulation of the theoretical model was performed by COMSOL Multiphysics (COMSOLAB, U.S.A.), magnetic field model. The principle of operation consists of two stages: "The first step was to evaluate the induced

eddy current by the excitation of an external coil, and the second step was to evaluate the induced magnetic fields by an eddy current." [29]. The presence of a coil on a fabric offers the privilege to use the coil as an antenna with two functionalities: Sensing element and data transfer element [28]. Another functionality could be charging coil for the accumulators when the clothes are not worn.

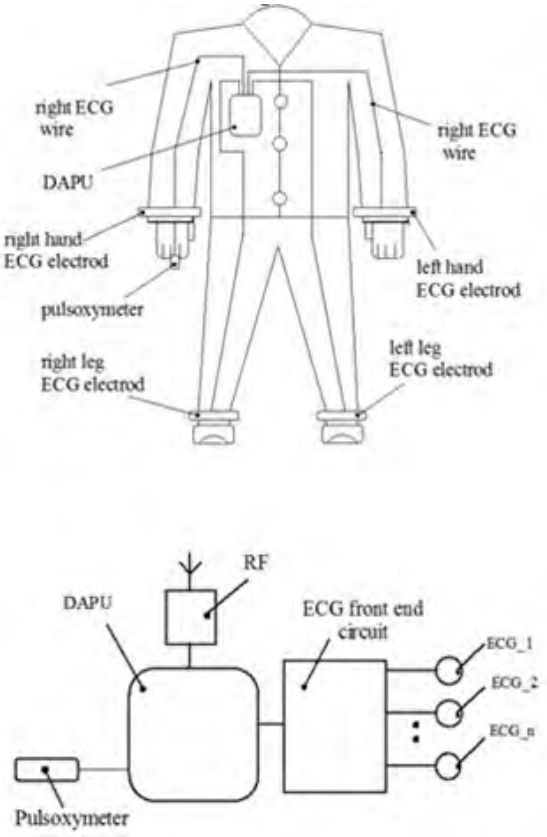


Figure 1. Smart clothing for Electrocardiography ECG [23].

In [30] a method dedicated to monitoring cardiorespiratory activity is presented that is based on the magnetic induction technique. The paper mentions that the capacitance between the coil and the body (denominated C_{stray}) did not influence the output signal, but during the physical activity this distance is not constant, therefore, in our opinion, the distance between the sensor and the thoracic plan has a large influence on the output signal value. The differences between [30] and our paper consist of:

(1) In [30] more sensors are used in order to determine the changes of the thoracic impedances, these changes being caused by cardiorespiratory activity. In this paper, we used only a sensor that is positioned in front of the apex and assesed the cardiorespiratory activity based on the changing of the thoracic impedance and of the distance between the sensor and thoracic surface. These parameters influence the inductance value of the sensor, this value is measured using a very sensitive inductance to digital convertor (LDC1612).

(2) In [30] inductive sensors based on the microcontroller MSP430F5435A are conceived and implemented. In this work, we used a dedicated inductance-to-digital convertor (LDC1612) that has very good sensitivity and measurement resolution (up to 28 bits).

In [31] a device for monitoring the pulse by measurement the bioimpedance of the thumb based on magnetic induction principle is described. An inductive sensor is placed on the thumb, as a ring, this method is an alternative for the photoplethysmographic sensors. This monitoring technique is able to determine the pulse only.

2. IoT and GreenCardio Platform

GreenCardio© [14] is a dedicated system to monitor the heart activity parameters using various mobile or wearable devices that are connected to a cloud. The system consists of a set of heart monitoring devices (wearable heart monitoring inductive sensor WHMIS, mobile electrocardiograph device, MED, being available to connect other kinds of peripherals), a data server and an application that represents a software platform for remote ECG investigation that is able to collect, centralize and diagnose ECG investigations.

The application runs as follows [14]:

(i) In the family doctor's office, as a separate module (FD, desktop), installed on a desktop computer or laptop that is connected to an ECG device, information regarding the ECG investigations will be stored initially on the local hard drive in a data base. Based on internet connection availability, the results of the ECG investigations will be transmitted to a central server to be parallel processed and monitored;

(ii) On a central server (collection/analysis, Web-based), where the centralizing, unification and pre-diagnosis algorithm running will be performed, as well as the creation of alerts based on results obtained from received investigations;

(iii) In the permanent monitoring center, the specialist doctor investigates the results with possible alerts stemming from highlighted probable pathologies resulting from the pre-processing's run on the central server, as is shown in Figure 2.

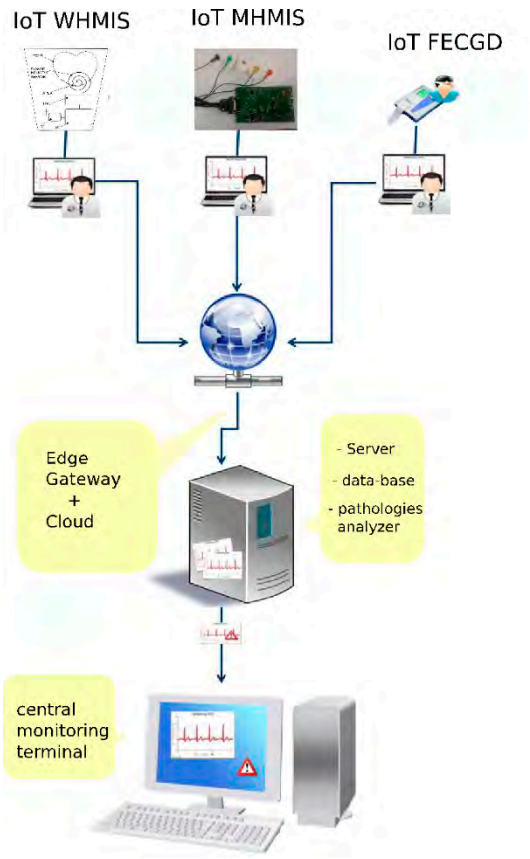


Figure 2. GreenCardioIoT system [14].

Workflow description

1. Creating a new patient form in the application in the FD (family doctor) module if the patient has not been registered beforehand.

2. Connecting the ECG equipment to the patient, controlling the ECG device through the FD module in order to complete the ECG investigation and collect the results in the local data base;
3. Visualizing the results of the investigation in the FD module (ECG graph);
4. Transmitting information regarding the patient (identification data, family doctor) and the results of the investigation to the central server;
5. Receive and store information on the central server;
6. Run automated analysis algorithms on the central server;
7. Showing information + automated analysis results + alerts in the monitoring screen/specialist doctor.

Automated pre-diagnosis

The functionality allows the doctor to perform a series of automated tests, that will ultimately result in annotations on the graph, in order to help the specialist doctor to better diagnose.

The application has a pre-diagnosis analysis, the classification of cardiac beats and viewing according to a predetermined classification.

By clicking on a button in the specialist doctor menu, the special signal line will be given annotations in relation to several pre-determined classes:

- Atrial extra systole = 0
- Normal beat = 1
- Left branch block = 2
- Right-left branch block = 3
- Ventricular extra systole = 4
- Aberrant intra-ventricular conduction = 6
- Stimulated ventricular rhythm = 8
- Fusion beat = 9

In a future version the following pre-diagnosis analyses will also be implemented:

a. R wave detection.
b. Computing the cardiac frequency with alert creation at frequencies larger than 130 beats per minute or lower than 40 beats per minute. An error in cardiac frequency calculus of ±10 beats/minute is admitted.
c. Computing the cardiac rhythm variation on a variable number of cardiac complexes. Alerts will be shown on a variation lower or higher than 20% of the cardiac rhythm and the graphical marking of the area.
d. Complex QRS detection. For each recording, a maximum of nine complex QRS misses will be acceptable.
e. Computing the median of the QRS complex. Alert generation at a median value of the QRS complex duration higher than 120 milliseconds.

This software component has been created as a desktop application that will be run on one or more computers at the monitoring center. Through this application, the specialist doctor has instant access to information regarding the medical form, current ECG investigation, and a complete history of past ECG investigations performed on a patient, regardless of the patient's location or the previous family doctor. The specialist doctor, through this component, gains access to visualizing and analysis instruments to be applied to the investigation result. Based on these, the specialist doctor may formulate recommendations or alerts, which can be sent instantly to the family doctor's office

On the investigation page, the family doctor can select the desired measurement instrument depending on time and signal strength. This can be achieved by checking the measurement box. Press the left mouse button and hold to select the desired section to be measured.

3. Experimental Model of the Wearable Heart Monitoring Inductive Sensor

The wearable sensor designs require some critical issues to be achieved as: Very low power consumption, small sizes, data storage, and data transfer capabilities, local data processing, and durability. The fulfillment of these conditions gives the portable sensors the quality of "wear and forget" devices.

The classification of the body movement intensity is difficult to be performed during the daily activity. Therefore, the results obtained during "slow motion", as they are presented in [31], are encouraging but they are not good enough to ensure a proper monitoring for all activities, this is one reason why we recommend to use such sensors for the repose and sleep activities only.

An LDC1612 circuit is used as inductance-to-digital convertor, as it has a resolution of 28 bits and is able to gather inductance data through two channels. The interface between LDC1612 and a host microcontroller is performed by I2C communication protocol (Figure 3a).

The architecture of the experimental model consists of a microcontroller, an LDC convertor, and a coil implemented in a planar configuration. In this version of implementation, the coil is attached on the fabric in front of the apex. The maximum effect of the heart activity can be detected in this thoracic region.

An L-C resonant is the core of the inductive sensor circuit that induces an EM field and its intensity is determined by inductance, capacitance, and frequency values. An object that is in the proximity of the sensor has an influence on it, according to the electromagnetic properties [29].

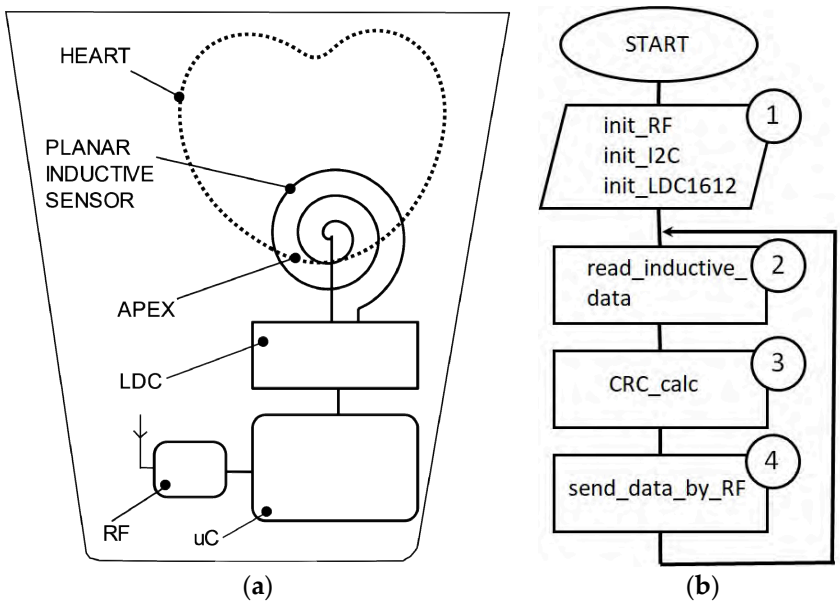


Figure 3. Experimental model block scheme: (**a**) Flowchart of the embedded software of inductive data acquisition and data transfer (**b**).

We consider a planar spiral to be an optimal shape of the inductance in order to be easily inserted in the fabric of the clothes. A planar spiral inductance is usually found in RF circuits [30] with several profiles: Square, circular, or polygonal. One expression of the planar spiral inductance according to [31] is:

$$L = K\_1\ \mu\_0\ (N\hat{}2\ D\_avg)/(1 + K\_2\ \phi)$$

where:

L = inductance (nH)
D_avg = average diameter of coil (mm)
K_1, K_2 = layout coefficients

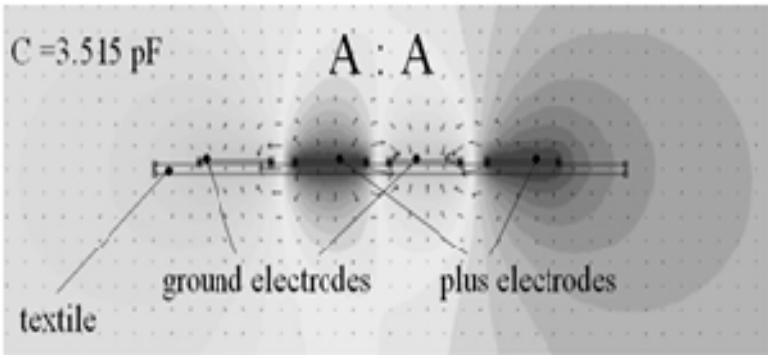
ϕ = fill factor
N = number of turns"

LDC1612 is a high resolution (28 bits) inductance-to-number convertor. The interface between the circuit and the microcontroller unit is performed by the I2C interface. The functionality is based on measuring the oscillation frequency of multiple LC resonators [31]. LDC1612 meets the parametric conditions required by a wearable device. The current consumption in sleep mode is under one microampere and in normal mode it is 1.5 milliampere. The range of power supply is 2.7–3.6 V, which can be powered by a long life or rechargeable lithium-ion battery. The data-rate of I2C interface is 400 kbps and the data-rate conversion is about 4 kSPS [31–35].

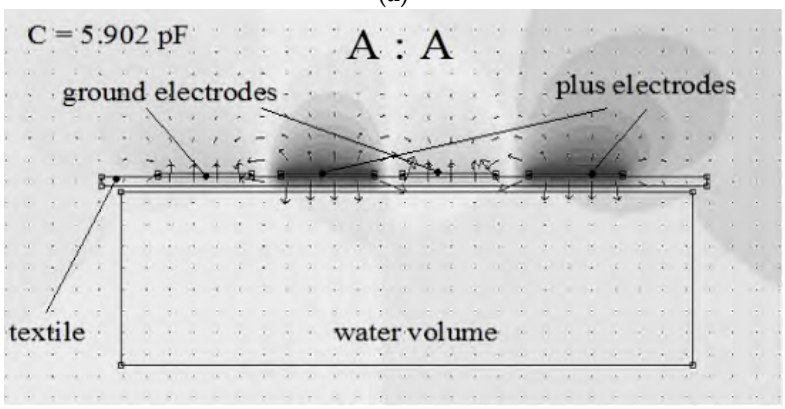
ADuCRF101 is a microcontroller unit that has a CORTEX M3 core incorporated and a configurable RF module. The current consumption in sleep mode is under one microampere.

The source code of the microcontroller is described in C language and is compiled by Keil tool. The program execution follows the successive operations described in the flowchart (Figure 4b), respectively. Label 1 represents the functions of initialization for the ADuCRF101 microcontroller and for the LDC1612 convertor. The setting of the microcontroller consists of: Clock frequency to 4 MHz, RF frequency: 868 MHz, RF data-rate: 300 kbps, length of the data stream: 24 bytes. LDC1612 is set up to work in continuous mode. Inductive data are stored in the internal RAM location as vectors having a length of 24 bytes.

The data are sent to a data concentrator that is connected to a laptop and are saved as text format. In order to avoid errors during the data transfer, a CRC algorithm is used. All the circuits are powered by a 3.6 V battery of and an energy capacitance of 2700 mAh. The average current during data acquisition is about 6 mA and during data transfer, it is about 36 mA (for an RF power of 13 dBm).



(**a**)



(**b**)

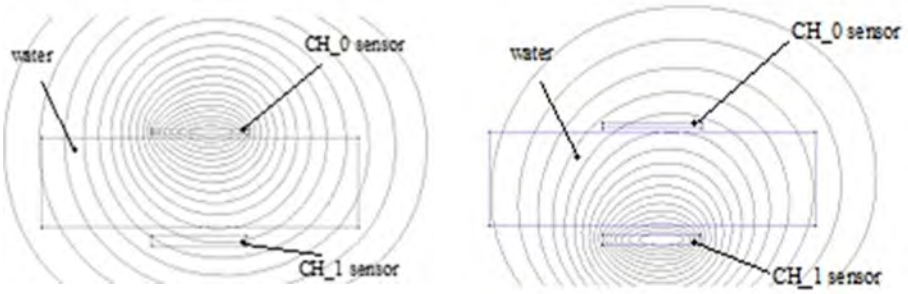
Figure 4. The electric field intensity of the sensor electrodes, simulated with Beladraw 1.0 software for an interdigital capacitance without water probe [24] (**a**) The electric field intensity of the sensor electrodes, simulated with Beladraw 1.0 software for an interdigital capacitance with water probe [24] (**b**).

The human biological tissues are mostly composed of water. The heart and the brain consist of about 73% water, the lungs 83% and the bones contain about 30% water [34]. Based on the influence of water on the electrical and electromagnetically field parameters, proximity sensors were conceived. The parameter of the electrical field that is strongly influenced by water is the electrical permittivity, respectively εr. The presence of a water body in the proximity of capacitance will strongly influence it, increasing its value.

Reference [24] presents the influence of a water probe on a planar capacitive sensor as simulation results using Beladraw 1.0 software (Figure 4a,b).

When a water probe is near electrodes, at a distance of 1 mm, the capacitance value increases to 5.902 pF. The proximity capacitive sensors have a very good sensitivity, but a disadvantage is the influence of environmental humidity on the measurement accuracy. In clothes applications, for example, perspiration is a factor to be considered.

In the case of the electromagnetic field, the influences of various materials that are found are increasing, decreasing or have no influence on the permeability parameter μr. The water diamagnetic property will have as an effect a decreasing of the inductance value, therefore, when the sensor approaches the tissues the value is less than when the sensor is placed at a larger distance (Figure 5a).



(**a**) (**b**)

Figure 5. Inductive proximity sensor: Simulated model. CH_0-activated (**a**) Inductive proximity sensor: simulated model, CH_1-activated (**b**).

Activating CH_0 determines the value of the inductance by the femm simulator as 3.45406 μH and when CH_1 sensor is activated (Figure 5a,b) the value of its inductance is 3.50515 μH. The water has a negative permeability due to its diamagnetic properties.

4. Mobile ECG Device

The main component of the portable device is the specialized integrated circuit ADAS1000 made by Analog Devices, which can work with 3, 4 or 10 electrodes (in a master–slave configuration) in order to obtain results on 3, 5 or 12 leads. The block diagram includes a microcontroller, the ADAS1000 circuit, a GSM/GPRS communication module, an accelerometer, and a temperature sensor.

The acceleration sensor detects if the patient is moving in order to make a correlation between the ECG data and the movement. The temperature sensor shows whether the patient has a fever. Beside the ECG information, the ADAS1000-integrated circuit also generates data on breathing, which is useful for the detection of sleep apnea.

During the ECG data reading, data communication is off, so that the signal input is not affected. After the reading interval of 10 s, the communication module GSM SIM900 is turned on and initialized. It contains a SIM card from a GSM data service provider. The microcontroller AduCRF101 from the portable device communicates with the GSM SIM 900 modem by means of a serial port and of GSM AT commands.

The SIM900 modem is a 2G GPRS mobile data module functioning in the GSM850 MHz, EGSM900 MHz, DCS1800 and PCS1900 frequency bands. The data read by the ADAS1000 circuit is processed by the microcontroller in order to be stored temporarily (RAM) or permanently (FLASH), and then they

are sent regularly through the GSM/GPRS data communication in the cloud to a GreenCardio© server by means of the FTP data protocol. If there is no Internet connection, the data is saved in internal FLASH memory and it is sent to the central server when the Internet connection is available.

The data is stored in a *.xml file. Its name indicates the day and the time of the data input, for example: 2018_07_26-14_01_20.xml. Within the GreenCardio© server, the data is processed individually for each patient and analyzed by a physician.

Such a file is presented below:

<?xmlversion="1.0" encoding="ISO-8859-1"?>
<!DOCTYPE RestingECG SYSTEM "rest.dtd">
<RestingECG>
<PatientID>Maria Popescu</PatientID>
<DateofBirth>01-08-1982</DateofBirth>
<Gender>Female</Gender>
<Waveform>
<WaveformType>Rhythm</WaveformType>
<NumberofLeads>1</NumberofLeads>
<SampleType>CONTINUOUS_SAMPLES</SampleType>
<SampleBase>500</SampleBase>
<Battery>Stare incarcare=0, Nivelbaterie=90%, Tensiunebaterie=4,061V</Battery>
<LeadData>
<LeadAmplitudeUnitsPerBit>2.84</LeadAmplitudeUnitsPerBit>
<LeadID>1</LeadID>
<LeadDataCRC32>4291035169</LeadDataCRC32>
<WaveFormData>FF 0000 0000 0000 FF 0000 0000 0000 FF 0000 0000 0000 FF 7FAD 8053 7FB6 FF 7F79 804D 7F6C FF 7E33 802A 7C0D 802D 7C0E FF 7D02 802D 7C0E FF 7D02 802D 7C0F FF 7D02 802D 7C0F FF 7D02 802D 7C0F00000</WaveFormData>
</LeadData>
</Waveform>
</RestingECG>

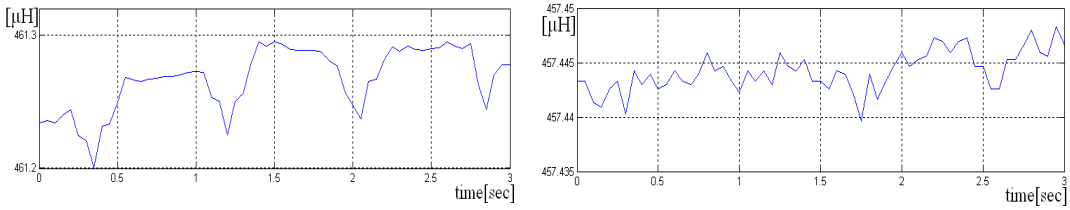
The above figure presents an ECG signal reading device made with two ADAS1000-integrated circuits connected as master and slave, which allows the representation of 12 derivations (member derivations and precordial derivations), as observed in Figure 6.

Figure 6. Experimental model using an ADAS1000 demo-board.

5. Data Acquisition

Inductive data generated by LDC1612 have 28 bytes size for each sample, but we use only the most significant 16 bits. The average length of each recording was approximately 30 s. The signals were acquired at the sampling frequency of f_s = 20 Hz. Two scenarios were used to acquire the signals, one in which the sensor is held "closer" to the chest and the other in which the sensor is not pressed.

In the following figure, we have a portion of an acquired signal holding the sensor closer to the chest box, where one can clearly see the periodicity of the heart-generated signal (Figure 7a).



(**a**) (**b**)

Figure 7. Sequence of three seconds from an acquisition with sensor pressed. The periodicity of signal is visible. (**a**) Sequence of three seconds from acquisition with sensor not pressed. The periodicity of signal is difficult to be detected (**b**).

If the sensor is not pressed, the signal has more noise, and the periodicity due to heart activity is less visible. A short sequence of three seconds from such signal is shown in Figure 7a,b. Even if the signal is noisy, it is still possible to detect the heart rate, if the size of the analysis window has more than 10 s.

Acquisitions were also made, in which the subject at first started breathing normally (with an air exhaled at about 3–5 s), and finally holding breath. This, way it was observed that in the first half of the signal, in which the subject does not breathe, the periodicity of the signal associated with the activity of the heart is more visible.

In the Figures 8–10 a pre-processed signal, filtering and normalization operators that were applied on this signal are presented, therefore, the values of interval was changed and the signal amplitude is not expressed in μH as it is adimensional. In future research activity, we intend to use DWT (discrete wavelet transform), by changing the detailed coefficients that contain also the noise, respectively, without altering the approximate coefficient as in work [36]. A predictive neural network could be implemented in order to increase the robustness to noise.

Because the heart rate detected for both parts of the signal was approximately the same, it was concluded that the implemented algorithm is as effective for both situations.

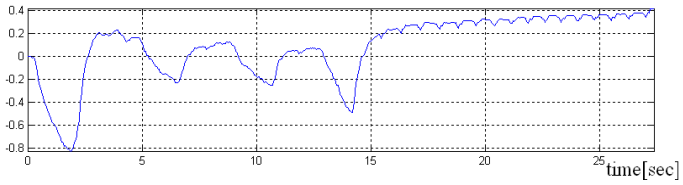
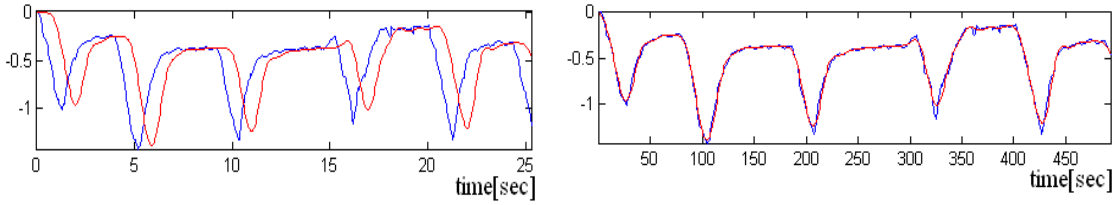


Figure 8. Acquisition with normal breath in the first part, and without breath in the second part of the signal.



(**a**) (**b**)

Figure 9. Representation of the delay between the input signal (with blue) and the filtered signal (with red) (**a**) Representation of the overlap of the input signal and the filtered signal (the delay was eliminated) (**b**).

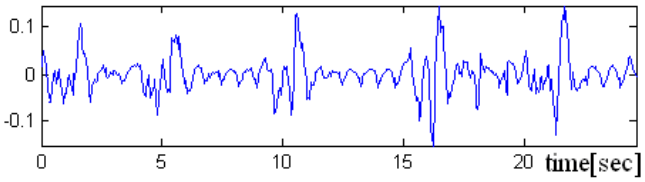


Figure 10. Representation of the difference signal (which mainly contains the periodic heart signal).

6. Data Processing and Results

Data processing consists of the implementation of an algorithm in order to extract two components, the respiration components, and the heart rate component from the same signal generated by the LDC circuit. Because the inductive sensor incorporates both these signals, $s = s_B + s_H$, we should find a filtering method in order to correctly split the target signals.

The algorithm is:

Step 1: Removing the amplitude offset from signal s

$$s_n = s_n - mean(s)$$

Step 2: Applying a low pass filter LPF with a cut-off frequency of 1 Hz, in order to extract the respiration components s_B:

$$s_n^* = \sum_{k=0}^{M-1} s_{n-k} \cdot b_k + \sum_{j=1}^{M-1} s_{n-j}^* \cdot a_j,\ s_n^* \cong s_B$$

The coefficients of the digital filter a_j, b_k are generated by Matlab and according to a filter that belongs to the Butterworth family having $M = 7$ order and the cut-off frequency as mentioned above, at 1 Hz.

The complete equation of the ARMA filter (autoregressive moving average) includes in the formula a recurrent part AR, that induces a delay in the filtered signal s^*.

Step 3: the delay between the inductive signal s and filtered signal s^* is determined using the AMDF (average magnitude difference function) method and the correlation function.

- initializing with zero of the vectors C_{XY} and D_{XY}

For k = 0: length_s-1

$$C_{XY}[k] = \sum_{n=0}^{N-k} s[n] \cdot s^*[n+k],\ k = 0, \ldots, N-1$$

$$D_{XY}[k] = \sum_{n=0}^{N-k} s[n] - s^*[n+k]$$

We denominated the number of samples/the length of the inductive signal (input signal) with N.

The C_{XY} and D_{XY} vectors calculation could be limited only for a number of values done by maximum delay where the signal could arrive and not on all length of s signal.

The offset is determined based on the global maximum position of the correlation function C_{XY}, respectively on the minimum global position from D_{XY} vector of AMDF.

$$offset(1) = \min_k D_{XY}$$

$$offset(2) = \max_k C_{XY}$$

Depending on the input signal, any of the two methods can determine better the offset. the time lag which has led to the best overlap is chosen (with a minimum difference).

$$\text{if } mean(d_1) < mean(d_2),$$

$$offset = offset(1),\ d = d_1$$

$$\text{else } offset = offset(2),\ d = d_2$$

The differences in signals between input signal s and the filtered signal s^* were calculated taking into account both delays.

$$d_j = \sum_{n=0}^{N-offset1} (s[n] - s^*[n - offset(j)],\ j = \{1,\ 2\}$$

Removing the respiration components s_B from the input signal will keep the heart rate component $s_H \cong d$

Step 4. The period T of the difference signal is estimated, using the autocorrelation function. The signal period T is considered to estimate the heart rate.

For k = 0: length_d-1

$$C_{XX}[k] = \sum_{n=0}^{N-k} d[n] \cdot d[n+k]$$

Only local peaks between $T_{\min}$ and $T_{\max}$ are taken into account. These limits are set by the minimum heart rate considered to be 40 bpm and the maximum value set at 200 bpm:

$$T_{\min} = 60/200 \cdot f_s,\ T_{\max} = 60/40 \cdot f_s$$

where $f_s = 20$ Hz is the signal sampling frequency.

The signal period is given by the local maximum position between the two previously set limits.

$$T = index\_of \max_k C_{XX}[k] k \in [T_{\min}, T_{\max}]$$

Step 5. The cardiac rhythm is estimated in the current analysis window as being:

$$bpm = 60/T \cdot f_s$$

Because the filtered signal s^* approximates the signal due to breathing very well, in the signal difference $d = s - s^* \cong (s_H + s_B) - s_B$ will be found the signal generated by the activity of the heart s_H, but also some high-frequency components of the signal s_B.

In addition to these high-frequency components, a noise is added that resembles uniform noise for recordings in which the sensor is not pressed/held close to the chest, but with all these impediments, heart rate detection can be performed. For these recordings, as noted above, the duration of the analysis window should be longer than 10 s.

The algorithm proposed by us has the advantage of simultaneously extracting both components, both of which are of interest because they can provide additional information about people suffering from certain diseases (e.g., apnea). The QRS complexes detection process is difficult, not only because of the physiological variability of QRS complexes, but also because of the different types of noise that an ECG signal contains.

The noise sources include muscle artifacts due to the motion of the electrodes, interference from power lines, the change in the baseline, T-waves with a high frequency similar to the QRS

complexes [37–40]. The artifacts are considered as external noises induced by muscle activities. The term "muscle noise artifact" is also found in other papers, an example could be [39].

Once the signal has been filtered, we applied a set of rules to correct QRS complexes detection [37,38]. In order to compare the heart rate values obtained with our system, the ECG signal was acquired in parallel using a BIOPAC system. The hardware modules used are the MP150A-CE data acquisition unit and the ECG100C, electrocardiogram amplifier modules with reusable EL258 electrodes. The MP150A allows simultaneous 16-channel acquisition with a sampling frequency up to a maximum of 200 kHz.

The sampling frequency we used was f_s = 200 Hz and the signals had a length of 30 s. The ECG100C module is a single channel and allows a gain between 500 and 5000. It is equipped with a high pass filter over frequencies of 0.05 Hz or 1 Hz, respectively, with a 35 Hz or 150 Hz low pass filter. It also has a notch filter to eliminate the 50 Hz frequency of the electrical network. Electrodes of the ECG100C mode were connected to measure Lead I (the two active electrodes being placed on the right arm and the stand arm, and the table electrode at the right foot). The acquisition was performed with 1Hz HPF in order to stabilize the baseline ECG. At this frequency, P and T waves may have slightly lower amplitude, but the QRS complex is not affected. Since the purpose of acquisition of these signals was to detect QRS peaks and to verify that the heart rate values obtained by the inductive sensor system we preferred this cutting frequency for HPF instead of 0.05 Hz. For the LPF filter the frequency 35 Hz ensures better noise elimination.

Even if these hardware filters were used to make the acquisition, additional software filters were required because some of the acquired signals had ECG baseline fluctuations (and the algorithm needed to be a straight line), respectively, the noise evenly high enough, the level of this noise also depending on how good the contact between the electrodes and the skin is.

The implemented algorithm has three main stages:

- baseline determination,
- detection of QRS complex,
- removing other information (where P and T).

7. Conclusions

The method of using inductive sensors is useful to monitor the data rate and the respiration, as vital signs, incorporating the "wear and forget" device in the clothes. The data rate signal and the respiration signal are extracted from the same output signal of inductance-to-number convertor.

The method and the wearable sensors incorporated in the clothes are suitable to monitor physiological moving parameters that have small amplitudes (e.g., mechanical heart activity, respiration, tremor, pulse, etc.) only if the body is in a repose position. Any muscle activity will induce artifacts in the signal generated by the sensors. Their influence will be proportional to the intensity of body movement. We take into account using an acceleration sensor in order to validate the inductive signal (when the body is in repose, without muscle activity) and to eliminate the artefacts based on correlation with the acceleration signal.

The body motion during data sampling has a large influence on the inductive signal inducing its motion artifacts and we concluded that this method is not suitable to be used in daily activity. During the daily activity it is difficult to perform a classification of the body movement intensity. Therefore, the results obtained during "slow motion" are encouraging but they are not good enough to ensure proper monitoring for all activities. This is one reason why we recommend using such sensors for the repose and sleep activities only.

The theme of our paper is to extract from the same signal, generated by the inductive sensor, two parameters: Respiration and heart rate. For the statistical comparison, we intend to use the representing data using Bland–Altman plots. In the future work, we propose to correlate the inductive sensors data with ECG data and acceleration data in order to implement other models for intelligent textiles, and to improve the GreenCardio System©.

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References

1. Internet of Things—Statistics & Facts. Available online: https://www.statista.com/topics/2637/internet-of-things (accessed on 14 January 2019).
2. Satija, U.; Ramkumar, B.; Manikandan, M.S. Real-Time Signal Quality-Aware ECG Telemetry System for IoT-Based Health Care Monitoring. *IEEE Internet Things J.* **2017**, *4*, 815–823. [CrossRef]
3. Spanò, E.; Di Pascoli, S.; Iannaccone, G. Low-Power Wearable ECG Monitoring System for Multiple-Patient Remote Monitoring. *IEEE Sens. J.* **2016**, *16*, 5452–5462. [CrossRef]
4. Yasin, M.; Tekeste, T.; Saleh, H.; Mohammad, B.; Sinanoglu, O.; Ismail, M. Ultra-Low Power, Secure IoT Platform for Predicting Cardiovascular Diseases. *IEEE Trans. Circuits Syst. I Regul. Pap.* **2017**, *64*, 2624–2637. [CrossRef]
5. Wu, F.Y.; Yang, K.D.; Yang, Z. Compressed Acquisition and Denoising Recovery of EMGdi Signal in WSNs and IoT. *IEEE Trans. Ind. Inform.* **2018**, *14*, 2210–2219. [CrossRef]
6. Hooshmand, M.; Davide, Z.; Tommaso, M.; Michele, R. SURF: Subject-Adaptive Unsupervised ECG Signal Compression for Wearable Fitness Monitors. *IEEE Access* **2017**, *5*, 19517–19535. [CrossRef]
7. Tekeste, T.; Saleh, H.; Mohammad, B.; Mohammed, I. Ultra-Low Power QRS Detection and ECG Compression Architecture for IoT Healthcare Devices. *IEEE Trans. Circuits Syst. I Regul. Pap.* **2019**, *66*, 669–679. [CrossRef]
8. Beach, C.; Krachunov, S.; Pope, J.; Fafoutis, X.; Piechocki, R.J.; Craddock, I.; Casson, A.J. An UltraLow Power Personalizable Wrist Worn ECG Monitor Integrated With IoTInfrastructure. *IEEE Access* **2018**, *6*, 44010–44021. [CrossRef]
9. Disi, M.A.; Djelouat, H.; Kotroni, C.; Politis, E.; Amira, A.; Bensaali, F.; Dimitrakopoulos, G.; Alinier, G. ECG Signal Reconstruction on the IoT-Gateway and Efficacy of Compressive Sensing Under Real-Time Constraints. *IEEE Access* **2018**, *6*, 69130–69140. [CrossRef]
10. Hooshmand, M.; Zordan, D.; Del Testa, D.; Grisan, E.; Rossi, M. Boosting the Battery Life of Wearables for Health Monitoring Through the Compression of Biosignals. *IEEE Internet Things J.* **2017**, *4*, 1647–1662. [CrossRef]
11. Harpe, P.; Gao, H.; van Dommele, R.; Cantatore, E.; van Roermund, A.H.M. A 0.20mm23 nW Signal Acquisition IC for Miniature Sensor Nodes in 65 nm CMOS. *IEEE J. Solid State Circuits* **2016**, *51*, 240–248.
12. Deepu, C.J.; Heng, C.H.; Lian, Y. A Hybrid Data Compression Scheme for Power Reduction in Wireless Sensors for IoT. *IEEE Trans. Biomed. Circuits Syst.* **2017**, *11*, 245–254. [CrossRef] [PubMed]
13. Djelouat, H.; Zhai, X.J.; Al Disi, M.; Amira, A.; Bensaali, F. System-on-Chip Solution for Patients Biometric: A Compressive Sensing-Based Approach. *IEEE Sens. J.* **2018**, *18*, 9629–9639. [CrossRef]
14. GreenCardio. Available online: http://greencardio.ro/index.html&EN (accessed on 5 May 2019).
15. Abdellatif, A.A.; Khafagy, M.G.; Mohamed, A.; Chiasserini, C.F. EEG-Based Transceiver Design With Data Decomposition for Healthcare IoT Applications. *IEEE Internet Things J.* **2018**, *5*, 3569–3579. [CrossRef]
16. Hussein, A.F.; N Kumar, A.; Burbano-Fernandez, M.; Ramírez-González, G.; Abdulhay, E.; de Albuquerque, V.H.C. An Automated Remote Cloud-Based Heart Rate Variability Monitoring System. *IEEE Access* **2018**, *6*, 77055–77064. [CrossRef]
17. Myers, J.; Savanth, A.; Gaddh, R.; Howard, D.; Prabhat, P.; Flynn, D. A Subthreshold ARM Cortex-M0+ Subsystem in 65 nm CMOS for WSN Applications with 14 Power Domains, 10T SRAM, and Integrated Voltage Regulator. *IEEE J. Solid State Circuits* **2016**, *51*, 31–44.

18. Constantinescu, A.; Geman, O.; Hagan, M. Tremor analysis in neurological disorders using intelligent clothes. In Proceedings of the IEEE E Health and Bioengineering Conference (EHB), Iasi, Romania, 19–21 November 2015; pp. 1–4.
19. Geman, O.; Sanei, S.; Costin, H.N.; Eftaxias, K.; Vysata, O.; Prochazka, A.; Lhotska, L. Challenges and trends in Ambient Assisted Living and intelligent tools for disabled and elderly people. In Proceedings of the 2015 International Workshop on Computational Intelligence for Multimedia Understanding (IWCIM), Prague, Czech Republic, 29–30 October 2015; pp. 1–5.
20. Chiuchisan, I.; Costin, H.N.; Geman, O. Adopting the internet of things technologies in health care systems. In Proceedings of the 2014 International Conference and Exposition on Electrical and Power Engineering (EPE), Iasi, Romania, 16–18 October 2014; pp. 532–535.
21. Stoppa, M.; Chiolerio, A. Wearable electronics and smart textiles: A critical review. *Sensors* **2014**, *14*, 11957–11992. [CrossRef]
22. Teodorescu, H.N. Textile-, conductive paint-based wearable devices for physical activity monitoring. In Proceedings of the 4th IEEE International Conference on E-Health and Bioengineering (EHB), Iasi, Romania, 21–23 November 2013.
23. Hagan, M.; Teodorescu, H.N. Intelligent Clothes with a Network of Painted Sensors. In Proceedings of the 4th IEEE International Conference on E-Health and Bioengineering (EHB), Iasi, Romania, 21–23 November 2013.
24. Hagan, M.; Geman, O. A wearable system for tremor monitoring and analysis. In Proceedings of the Romanian Academy, Series A, Iasi, Romania, 2 November 2016; Volume 17, pp. 90–98.
25. Amarandei, L.A.; Hagan, M.G. Chapter 22: Wearable, assistive system for monitoring people in critical environments. In *Improving Disaster Resilience and Mitigation—IT Means and Tools*; Teodorescu, H.N., Kirschenbaum, A., Cojocaru, S., Bruderlein, C., Eds.; Springer: Berlin/Heidelberg, Germany, 2014; pp. 335–344. [CrossRef]
26. Asada, H.; Shaltis, P.; Reisner, A.; Rhee, S.; Hutchinson, R.C. Mobile Monitoring with Wearable Photoplethysmographic Biosensors. *IEEE Eng. Med. Biol. Mag.* **2003**, *22*, 28–40. [CrossRef]
27. Gibbs, P.; Asada, H.H. Reducing motion artifact in wearable biosensors using mems accelerometers for active noise cancellation. In Proceedings of the Proceedings of the 2005, American Control Conference, Portland, OR, USA, 8–10 June 2005. [CrossRef]
28. Gi, S.O.; Lee, Y.J.; Koo, H.R.; Khang, S.; Kim, K.N.; Kang, S.J.; Lee, J.W. Application of a Textile-based Inductive Sensor for the Vital Sign Monitoring. *J. Electr. Eng. Technol.* **2015**, *10*, 364–371. [CrossRef]
29. Teichmann, D.; Kuhn, A.; Leonhardt, S.; Walter, M. The MAIN Shirt: A Textile-Integrated Magnetic Induction Sensor Array. *Sensors* **2014**, *14*, 1039–1056. [CrossRef]
30. Teichmann, D.; Foussier, J.; Löschcke, D.; Leonhardt, S.; Walter, M. MonitoRing—Magnetic induction measurement at your fingertip. *J. Phys. Conf. Ser.* **2013**, *434*, 012084. [CrossRef]
31. Eroglu, A. Planar inductor design for high power applications. *Prog. Electromagn. Res. B* **2011**, *35*, 53–67. [CrossRef]
32. LDC1612, LDC1614 Multi-Channel 28-Bit Inductance to Digital Converter (LDC) for Inductive Sensing. Available online: http://www.ti.com/product/ldc1612/datasheet (accessed on 4 December 2016).
33. LDC1612 Evaluation Module for Inductance to Digital Converter with Sample PCB Coils. Available online: http://www.ti.com/tool/ldc1612evm (accessed on 4 August 2018).
34. Koo, H.R.; Lee, Y.J.; Gi, S.; Khang, S.; Lee, J.H.; Lee, J.H.; Lin, M.G.; Park, H.J. The effect of textile-based inductive coil sensor positions for heart rate monitoring. *J. Med. Syst.* **2014**, *38*, 2. [CrossRef] [PubMed]
35. Mohan, S.S.; del Mar Hershenson, M.; Boyd, S.P.; Lee, T.H. Simple accurate expressions for planar spiralinductances. *IEEE J. Solid State Circuits* **1999**, *34*, 1419–1424. [CrossRef]
36. Okada, S.; Fujiwara, Y.; Yasuda, M.; Ohno, Y.; Makikawa, M. Non-restrictive Heart Rate Monitoring Using an Acceleration Sensor. In Proceedings of the 28th IEEE EMBS Annual International Conference, New York, NY, USA, 30 August–3 September 2006; pp. 5093–5096.
37. Pan, J.; Tompkins, W. A Real-Time QRS Detection Algorithm. *IEEE Trans. on Biomed. Eng.* **1985**, *32*, 230–236. [CrossRef] [PubMed]
38. Barleanu, A.; Hagan, M.; Geman, O.; Chiuchisan, I. Wearable ballistocardiography system for heartbeat detection. In Proceedings of the Electrical and Power Engineering (EPE), Iasi, Romania, 20–22 October 2016; pp. 294–298.

39. Paul, S.; Reddy, M.R.; Kumar, V.J. A transform domain SVD filter for suppression of muscle noise artefacts in exercise ECG's. *IEEE Trans. Biomed. Eng.* **2000**, *47*, 654–663. [CrossRef] [PubMed]
40. Slama, A.B.; Lentka, L.; Mouelhi, A.; Diouani, M.F.; Sayadi, M.; Smulko, J. Application of statistical features and multilayer neural network to automatic diagnosis of arrhythmia by ECG signals. *Metrol. Meas. Syst.* **2018**, *25*, 87–101.

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A Novel Blunge Calibration Intelligent Feature Classification Model for the Prediction of Hypothyroid Disease

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Abstract: According to the Indian health line report, 12% of the population suffer from abnormal thyroid functioning. The major challenge in this disease is that the existence of hypothyroid may not propagate any noticeable symptoms in its early stages. However, delayed treatment of this disease may lead to several other health problems, such as fertility issues and obesity. Therefore, early treatment is essential for patient survival. The proposed technology could be used for the prediction of hypothyroid disease and its severity during its early stages. Though several classification and regression algorithms are available for the prediction of hypothyroid using clinical information, there exists a gap in knowledge as to whether predicted outcomes may reach a higher accuracy or not. Therefore, the objective of this research is to predict the existence of hypothyroidism with higher accuracy by optimizing the estimator list of the pycaret classifier model. With this overview, a blunge calibration intelligent feature classification model that supports the assessment of the presence of hypothyroidism with high accuracy is proposed. A hypothyroidism dataset containing 3163 patient details with 23 independent and one dependent feature from the University of California Irvine (UCI) machine-learning repository was used for this work. We undertook dataset preprocessing and determined its incomplete values. Exploratory data analysis was performed to analyze all the clinical parameters and the extent to which each feature supports the prediction of hypothyroidism. ANOVA was used to verify the F-statistic values of all attributes that might highly influence the target. Then, hypothyroidism was predicted using various classifier algorithms, and the performance metrics were analyzed. The original dataset was subjected to dimensionality reduction by using regressor and classifier feature-selection algorithms to determine the best subset components for predicting hypothyroidism. The feature-selected subset of the clinical parameters was subjected to various classifier algorithms, and its performance was analyzed. The system was implemented with python in the Spyder editor of Anaconda Navigator IDE. Investigational results show that the Gaussian naive Bayes, AdaBoost classifier, and Ridge classifier maintained the accuracy of 89.5% for the regressor feature-selection methods. The blunge calibration regression model (BCRM) was designed with naive Bayes, AdaBoost, and Ridge as the estimators with accuracy optimization and with soft blending based on the sum of predicted probabilities of classifiers. The proposed BCRM showed 99.5% accuracy in predicting hypothyroidism. The implementation results show that the Kernel SVM, KNeighbor, and Ridge classifier maintained an accuracy of 87.5% for the classifier feature-selection methods. The blunge calibration classifier model (BCCM) was developed with Kernel SVM, KNeighbor, and Ridge as the estimators, with accuracy optimization and with soft blending based on the sum of predicted probabilities of classifiers. The proposed BCCM showed 99.7% accuracy in predicting hypothyroidism. The main contribution of this research is the design of BCCM and BCRM models that were built with accuracy optimization with soft blending based on the sum of predicted probabilities of classifiers. The BCRM and BCCM models uniqueness's are achieved

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by updating the estimators list with the effective classifiers and regressors that suit the application at runtime.

Keywords: machine learning; regression; outlier; MAE; MSE; EVS

1. Introduction

For the accurate diagnosis of thyroid illness, functional data from the thyroid gland must be interpreted. Hypothyroidism is a condition where the thyroid gland in the body is unable to secrete thyroid hormone. Women are eight times as likely as males to suffer a thyroid condition. The thyroid condition tends to worsen and persist with ageing and may affect adults differently compared with children. The thyroid gland mainly helps in controlling the body's metabolism. Globally, thyroid disorders have begun to become more prevalent. For instance, one in eight women in Romania suffers from thyroid cancer. Approximately 30% of Romanians have endemic goiters. A limited diet, the use of drugs, anxiety, sickness, trauma, pollutants, and other elements can all affect thyroid function. Predetermined data sets can be categorized using classification, and this is a crucial supervised learning data-mining approach.

2. Literature Review

We examined, using machine learning, the thyroid data included in UC Irvine's knowledge discovery archive [1]. Thyroid disease has been classified as a common thyroid dysfunction in the general population. Our findings demonstrate the great accuracy of each of the aforementioned classification models, in which the decision tree model has the highest categorization rate. The infrastructure for creating and evaluating the models was provided by the KNIME analytics platform and Weka, which are two data-mining applications [2]. Classification is commonly used in the healthcare sector to inform business choices, diagnose patients, and provide them with exceptional care [3].

The precise estimation of thyroid gland operational information is critical for thyroid diagnosis. The thyroid gland mainly aids in the control of an individual's metabolism. The types of thyroid disease are determined by the production of either too little or too much thyroid hormone. Various neural networks have been used in this study to aid in the analysis of thyroid disease [4]. These networks aimed to diagnose thyroid disease by using a new hybrid machine-learning method that includes our classification system. A method for solving this diagnosis problem via classification was obtained by hybridizing AIRS with an advanced fuzzy weighted pre-processing. A cross-validation analysis was used to determine the technique's soundness for sampling variability [5]. A novel hybrid machine learning approach that incorporates this classification system was used to identify thyroid illness. AIRS and sophisticated fuzzy weighted pre-processing were combined to create a strategy for categorizing this diagnostic issue. By using cross-validation analysis, the technique's robustness for sampling variability was evaluated [6]. The expansion of scientific knowledge and the massive production of data have resulted in an exponential growth in databases and repositories. One of these rich data domains is the biomedical domain. A large amount of biomedical data is available, ranging from clinical symptom details to various types of biochemical data and imaging device outputs. Mechanically retrieving biological information from images and reshaping them into machine-readable knowledge is a challenging task, because the biomedical domain is vast, dynamic, and complicated. Data mining can improve the quality of biomedical pattern extraction [7].

A backpropagation algorithm is an early method for the detection of thyroid disease. An advanced neural network (ANN) was created using backpropagation of error for prior disease diagnosis. Afterward, this ANN was trained using empirical values, and testing was performed using information that had not been used during the training process [8]. Data collection is an important methodological approach in the field of medical disciplines,

because efficient techniques for analyzing and identifying disorders are required. Data mining applications are used in clinical governance, health information technology, and patient care systems. It is also important in determining disease resilience. The popular data mining techniques used to recognize the complex parameters of the nutrition data set are classification and clustering [9].

A novel approach was used for the detection of three types of anomalous red blood cells, known as poikilocytes, that were found in iron-deficient blood smears. The classification and counting of poikilocytes are critical steps in the rapid recognition of iron deficiency anemia disease. The three basic poikilocytes in IDA are dacrocyte, elliptocyte, and schistocyte [10]. High-dimensional biomedical datasets contain thousands of features that are used to diagnose genetic diseases, but their predictive accuracy is affected by numerous irrelevant or weak connection features. While minimizing computation complexity in data mining, feature-selection techniques enable classification models to precisely discover patterns in features and determine a feature vector from an initial set of features. An enhanced shuffled frog-leaping algorithm (ISFLA) is presented in this paper, and it explores the space for potential subsets to choose the set of attributes that maximizes prognostication while minimizing irrelevant attributes in high-dimensional biological data [11]. The latest ANN-based finite impulse response extreme learning machine (FIR-ELM) was used to further analyze the categorization of two binary bioinformatics datasets into leukemia and colon tumor. To investigate the hidden layer of the neural classifier's FIR-ELM for the smoothing capabilities of feature identification, we performed a time series analysis of the microarray samples. Afterward, we determined how linearly divergent the data patterns in the microarray datasets were [12].

The optimal feature-selection problem, and its authors, describe a coherent analytical foundation that can retrofit successful heuristic criteria, indicating the approximate solutions made by each method [13]. The outcome of a microstructure heart arrhythmia detection system based on electrocardiography, ECG, and signal features was analyzed. These signals came from the MIT/BIH arrhythmia directory. Initially, Hermitian basis functions were used to model the ECG beats. The width parameter—sigma—of HBF was optimized in this step to minimize model error. The extracted features, which contain the model's boundary conditions, were used as input for the k-nearest neighbor classifier, KNN, to evaluate the model's effectiveness [14]. Approximately 90% of patients with Parkinson's disease are predicted to have vocal and speech issues. Vocal folds are often weakened by this infection, causing the patients to have an unnatural voice. In the present study, different samples from the auditory signal of patients with Parkinson's disease and healthy individuals were gathered. The data classification was then completed using the KNN classification approach based on varied amounts of optimized features after the optimized features that influenced the data classification process were determined using a genetic algorithm [15]. Although thrombolysis reduces impairment and increases survival rates in patients with ischemic stroke, some people continue to suffer detrimental effects. Consequently, it will be beneficial, when making health decisions, to predict how patients with myocardial infarction might react to regional rehabilitation [16].

Straightforward, mathematical assessment criteria need to be established to generate and quantify pragmatic forecasts in cerebral ischemia with data that are readily available post-surgery in the emergency unit. Regression was used to investigate the causes of inferior outcomes in the originating sample of formerly independent people with information systems. The covariate correlations from the computed holistic framework were used to build a scoring model based on integers for each correlation coefficient, and the average of the scores for the criterion was used to obtain the total result [17]. This process aims to offer a self-contained method for improving learning-argumentation frameworks that employ deformation key frames of MR images to aid in the rational frameworks of ischemic stroke diagnosis. Anthropological, physiological, and statistical approaches were gathered from the fragmented tumors to form a feature set that was then further defined using classification techniques. The results of the recommended approach, which accurately

designates electromagnetic fields as vascular tumors with a 93.4% accuracy, are significantly superior to those of the classification model [18]. Among many other clinical and imaging parameters, ageing and the severity of a hemorrhage are immediate, precise indicators of the likelihood of SICH and the results of treatment following intravenous infusion therapy [19]. The use of aided technology for stroke could reduce the evaluation period, improve prediction performance, make it simpler to discriminate between different types of ICH, and reduce the chance of human error [20].

One study presents the improvements in learning methods and developments that are in line with the different varieties and manifestations of dyslexia. This study opens with a discussion of cosmic mythology and examines how learning environments that consider student's skills and requirements can be combined with the appropriate assistive technology to deliver effective e-learning experiences and reliable instructional resources. The Ontology Web Language, a data-handling framework that enables programmers to handle both the substance and the introduction of the data available on the web, was used to generate the metaphysics used in this evaluation [21]. The methodology was designed and implemented to help identify the fundamental problems that may affect students learning to read or write and problems that may then lead to further problems with memory cognition. This strategy was used to assist activists and parents in understanding the issue of dyslexia and to put children on the right path to academic success [22]. Participants, with and without dyslexia, used an online game with language-independent melodic and visual components to communicate in different languages. A total of 178 participants were involved. The analysis revealed nine game measures for Spanish children with and without dyslexia that had significant differences and which could be used in current projects as a justification for speech independent exploration [23]. Quantitative and artificial intelligence-based methods are recommended to instinctually seek innovative and complicated features that consider reliable credentials among dyslexic and control listeners and to support the hypothesis that the majority of differences between dyslexic and talented readers are located on the left side of the brain. Unexpectedly, these devices have also demonstrated how high pass signals carry vital information [24]. Their analysis revealed certain remarkable EEG patterns associated with autism, which is a learning disability with a neurological basis. Although EEG signals contain important information about mental processes, understanding these practices is typically indirect because of their intricate nature. This approach identifies the optimal EEG terminals and brain regions for order and the extraordinary EEG signals produced during writing and composition in adults with dyslexia [25]. The central idea is to begin creating code language for scripting matrices by using the Boolean algebra features of the codes and to present two decryption techniques that enable the identification and retrieval of potential faults or rejection [26]. Dynamic subsamples of ocean climate predictions of surface temperature anomalous outliers in the Tasman Sea were enhanced by the employment of reports of extreme sea-surface temperature that derived from the space station's geographical position system. The parameters of an extreme value distribution were predicted using regression analysis on the important marine meteorological data in a probabilistic conceptual structure [27]. Additional or standardized nuclear approaches can be employed to overcome the constraints of current investigations into the original sources of seafood. Cross luminescence and carbon isotope analysis have been used to pinpoint the production method and geographic origin of Asian freshwater fish [28].

Security concerns that develop during earthquake activity and during periods when the threat of earthquake activity is at its peak, should always be handled probabilistically [29]. For this study, the two quantifiable methods for estimating the likelihood of seismic behavior to affect important and relatively low- and mid-rise structures are presented. The non-linear and linear systems separately and simultaneously assess the injury concerns of an inclined plane exposed to uncontrollable shaking and atmospheric threats, respectively. These systems are divided into three parts: danger showcase; underpinning delicacy examination; and destruction likelihood processing [30].

Numerous well-known classification methods, such as decision tree, ANN, logistic regression, and naive Bayes were examined for one study. Then, bagging and boosting procedures were created to increase the durability of these frameworks. Additionally, random forest was considered when the investigation was evaluated. The best result of the sickness risk random-forest strategy was employed for classification according to outcomes. Subsequently, a web application for predicting future occurrences was created using this approach. People with higher chance of getting diabetes were included in the diabetes risk class [31]. Heart rate variation information derived from ECG signal data were used for a further investigation. Here, when CNN-LSTM was originally tested with the HRV data, the prediction accuracy was 90.9%. By using CNN-LSTM integration, the accuracy was improved to 95.1%, and by using five-fold cross-validation based on the same data, the efficiency was enhanced to 93.6%. The cross-validation efficiency is the maximum priority currently available for the automatic identification of hypertension [32]. The information was subjected to several machine-learning approaches, and categorization was carried out using a range of strategies, in which regression analysis resulted in the highest accuracy of 96%. With a 98.8% accuracy rate, the AdaBoost classifier was the pipeline's most appropriate prediction. Two independent datasets were used to compare the accuracy of the machine-learning methods. The algorithm clearly enhanced the diabetes prediction accuracy and precision when utilizing this information compared to previous resources [33].

Additionally, the mellitus dataset was used to evaluate the effectiveness of various suggested deep neural networks and machine learning classification techniques. The other methods had an accuracy that is higher than 90%; for instance, the XGBoost classifier achieved a performance of approximately 100.0% [34]. Both cutting-edge methodologies and some well-known machine learning strategies were contrasted with the DNN algorithm. The suggested technique, which is dependent on the DNN technique, delivered impressive outcomes, with an accuracy of 99.75% and an F1-score of 99.66% [35]. Some papers have been published by authors that report the application of SVM, KNN, or other ML tools in biomedical applications [36–40]. Automated medical diagnostic systems can be easily accessed by the general public, especially by those who cannot afford quality medical care. This methodology essentially combines soft and harsh inputs. A wide range of typical symptoms, including fever, headaches, and cough, were considered soft inputs. Each chosen illness was associated with a range of universal symptoms. Images of the tongue were considered hard inputs because doctors frequently utilize them to identify a variety of illnesses. Hard input analysis was split into two stages: chromatic color analysis and statistical analysis based on texture. After being decoded from the hard and soft inputs, the feature vectors were supplied to a neural network to create a classification mode [41].

3. Research Methodology

A hypothyroidism dataset from the UCI containing 3163 patient details with 23 independent features and one dependent feature (https://archive.ics.uci.edu/ml/datasets/thyroid+disease, accessed on 12 January 2023) was used as shown in Equation (1).

$$HY = \{[H1, H2, H3, \ldots\ldots\ldots.., H23], [D]\} \quad (1)$$

where HY represents the hypothyroid dataset.

We undertook dataset preprocessing and determined its incomplete values. The incomplete data were computed for the hypothyroidism dataset by computing the mean of input values for each attribute with Equation (2).

$$HY_{ij} = \frac{1}{23} \sum_{i=1}^{23} \sum_{j=1}^{3163} \sum_{v=1}^{23} \left(HY_{ij}\right)^{v} \quad (2)$$

Equation (2) expresses the estimation of the null data information and attribute scaling of the vehicle motion dataset with Equation (3).

$$HY' = \frac{1}{23}\sum_{V=1}^{23}\left(HY'_{HY}\right)^{V} \tag{3}$$

where HY' is the complete processed dataset without null values. The imputation deviation of features was measured using the average of the estimated variance within the hypothyroidism dataset as shown in Equation (4).

$$HY' = \frac{1}{23}\sum_{V=1}^{23}\left(HY'_{HY}\right)^{V} = \frac{1}{23}\sum_{v=1}^{23}\left(variance\left(HY'_{HY}\right)^{v}\right) \tag{4}$$

The imputed dataset was estimated with the interval value "*Interval*"of each feature by finding its variance and was estimated using Equation (5).

$$Interval = HY' - \frac{1}{v-1}\sum_{v=1}^{7} HY' - \sum_{v=1}^{23}\left(variance\left(HY'_{HY}\right)^{v}\right. \tag{5}$$

The overall architecture of the work is shown in Figure 1. The following contributions are provided in this work.

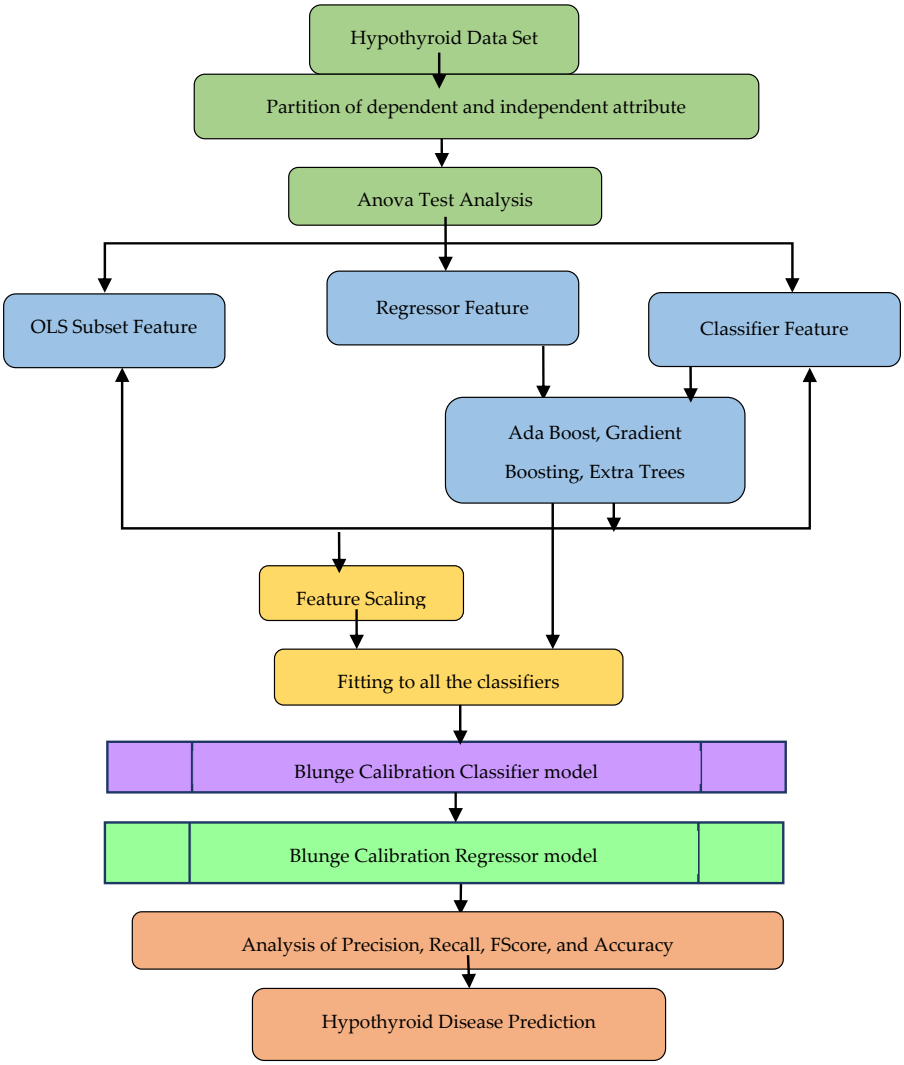

Figure 1. Proposed system workflow.

The complete processed data including incomplete values that contained the complete variance were estimated using Equation (6) as follows:

$$FinalHY = HY' + \left(\frac{v+1}{v}\right) \times Interval \tag{6}$$

An exploratory data analysis was performed to analyze all the clinical parameters and the extent to which each feature supports the prediction of hypothyroidism. The number of parameters, the correlation of all variables, as in the following equation, and the data type of the characteristics as given in Equation (7), were evaluated by subjecting a dataset to exploratory prescriptive data analysis.

$$corr = \left[\frac{\sum_{h=1}^{123}(HY_h - \underline{HY})\ \sum_{d=1}^{1}(D_d - \underline{D})}{\sqrt{\sum_{h=1}^{18}(HY_h - \underline{HY})^2}\sqrt{\sum_{d=1}^{1}(D_d - \underline{D})^2}}\right] \tag{7}$$

As stated in Equations (8)–(10), the dataset was divided into training and testing data with an 80:20 ratio. Python script was used for the implementation by using the Spyder platform and Anaconda navigator.

$$Train(\underline{HY}) = \frac{80\ percent\ of\ (Rand)^2}{hy}\frac{(HY - hy)}{HY} \tag{8}$$

$$Test(\underline{HY}) = \frac{20\ percent\ of\ (Rand)^2}{hy}\frac{(HY - hy)}{HY} \tag{9}$$

$$(Rand)^2 = \left[\frac{\sum_{h=1}^{23}(HY_h - HY_h)^2}{HY_h - 1}\right] \tag{10}$$

ANOVA test was carried out to verify the F-statistic values of all features with a PR(>F) <0.05 that highly influence the target. Then, hypothyroidism was predicted using various classifier algorithms, and the performance was analyzed. The original dataset was subjected to normalization in order to make it ready for application of the ANOVA test. This is achieved by using the Box–Cox method from the statistical package of NumPY and pandas. The Box–Cox approach transforms and normalizes the data to handle non-normally distributed data. The results obtained from the Box-Cox method is shown below in Figure 2.

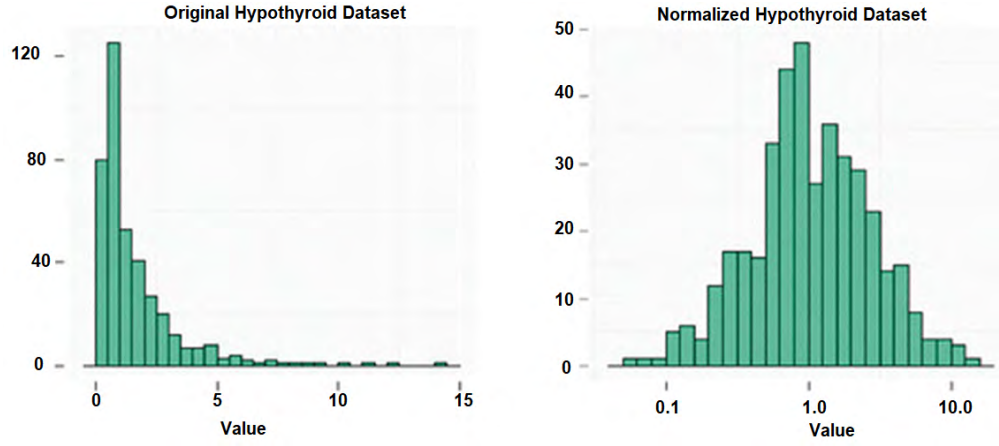

Figure 2. Normalization of the hypothyroidism dataset.

The original dataset was subjected to dimensionality reduction using the regressor and classifier feature-selection algorithms to determine the best subset components for predicting hypothyroidism. The feature-selected subset of the clinical parameters was

subjected to various classifier algorithms, and the performance was analyzed using the specified metrics. The implementation was carried out with python in Spyder editor with Anaconda Navigator IDE. Investigational results show that the Gaussian naive Bayes, AdaBoost classifier, and Ridge classifier maintained an accuracy of 89.5% for the regressor feature selection methods. The blunge calibration regression model, as shown in Figure 3, was created with naive Bayes, Ada boost, and Ridge as the estimators with accuracy optimization using soft blending based on the sum of predicted probabilities of classifiers as shown in Equations (11)–(15).

$$GuassianNB = \frac{1}{\sqrt{2\pi\sigma_h^2}}\, exp\left(-\frac{(HY_h - Mean_s)^2}{2\sigma_s^2}\right) \tag{11}$$

$$Adaboost = \frac{\sum_{h=1}^{23}\left(D_d - HY_h^{23}\,\hat{\beta}\right)^2}{2} + \lambda\left(\frac{1-\alpha}{2}\,\sum_{h=1}^{23}\hat{\beta}_h^2 + \alpha\sum_{h=1}^{23}\left|\hat{\beta}_h^2\right|\right) \tag{12}$$

$$\hat{\beta} = argmin\left[\sum_{s=1}^{9}\left|(D_d) - \sum_{h=1}^{23}(HY_h)\right|\right] \tag{13}$$

$$Ridge = \lambda\left(\frac{1-\alpha}{2}\,\sum_{h=1}^{23}\hat{\beta}_h^2 + \alpha\sum_{h=1}^{23}\left|\hat{\beta}_h^2\right|\right) \tag{14}$$

$$BCRM = Estimator\{(GuassianNB,\ Adaboost,\ Ridge)\} \tag{15}$$

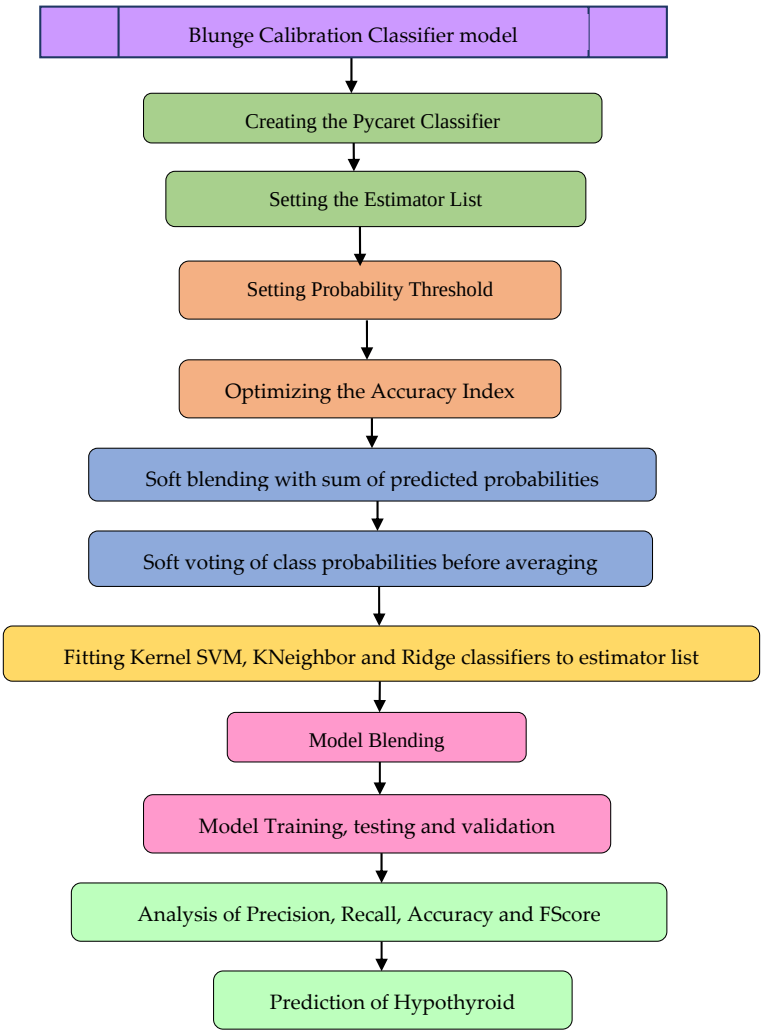

Figure 3. Blunge calibration classifier model workflow.

The implementation results show that the Kernel SVM classifiers, KNeighbor classifier, and Ridge classifier maintained an accuracy of 87.5% for the classifier feature-selection methods. The blunge calibration classifier model, as shown in the Figure 4, was created with Kernel SVM, KNeighbor, and Ridge as the estimators with accuracy optimization using soft blending based on the sum of predicted probabilities of classifiers as shown in Equations (16)–(19).

$$KNN(HY,\ D) = \sqrt{\sum_{v=1}^{23}(HY_h - D_h)^2} \tag{16}$$

$$kernel\left(HY,\ HY'\right) = exponential\left(\frac{[-\|HY - VHY'\|]^2}{2\sigma^2}\right) \tag{17}$$

$$kernelSVM(HY) = \sum_{v=1}^{7} \propto \times B \times kernel\left(HY,\ HY'\right) + vector \tag{18}$$

$$BCCM = Estimator\{(KNN,\ kernelSVM,\ Ridge)\} \tag{19}$$

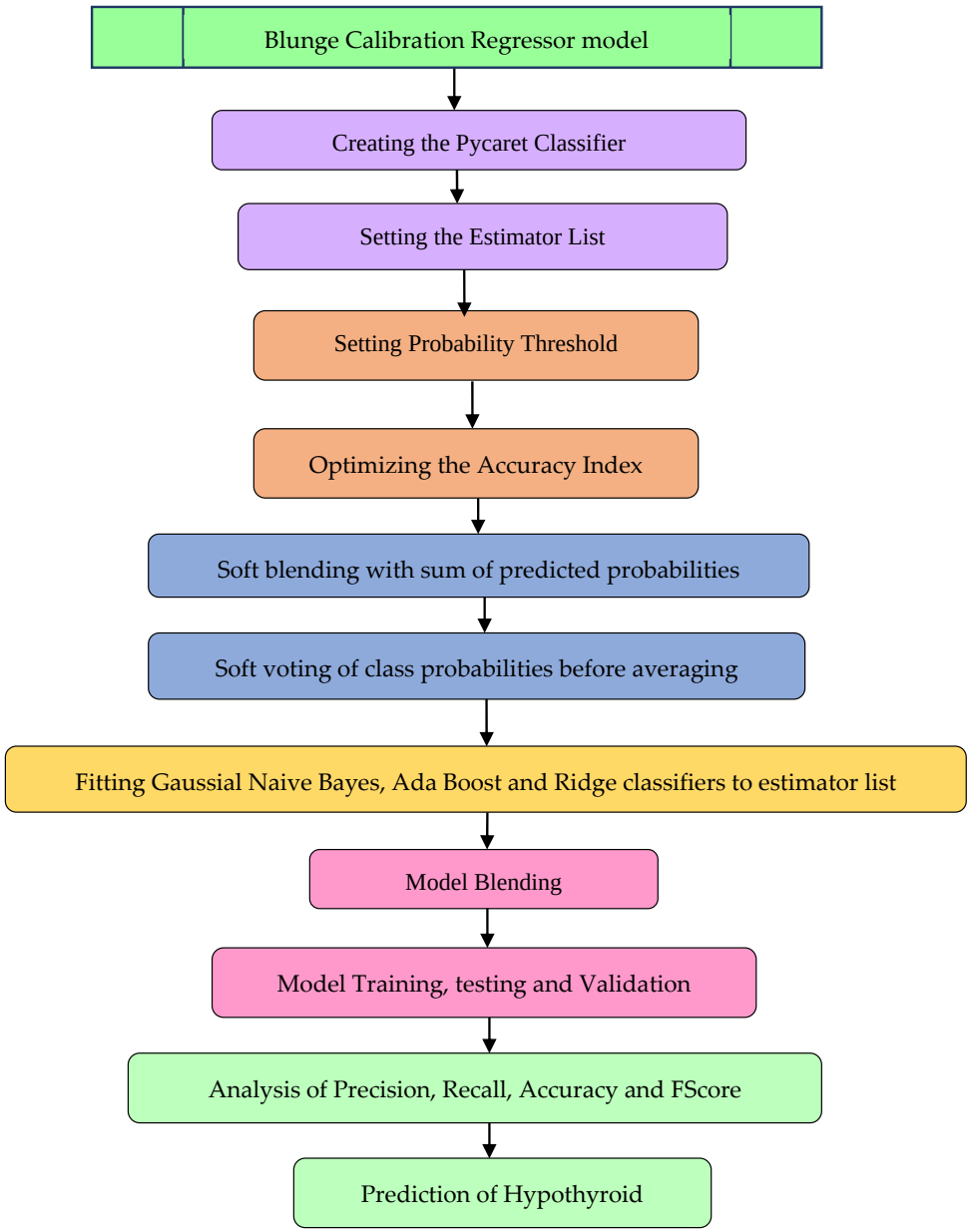

Figure 4. Blunge calibration regressor model workflow.

4. Implementation Setup

The hypothyroid dataset with 3163 rows and 24 feature components from UCI was used for data preprocessing. The dataset information is shown in Figure 5.

```
RangeIndex: 3163 entries, 0 to 3162
Data columns (total 24 columns):
Age                          2717 non-null float64
Sex                          3163 non-null int64
on_thyroxine                 3163 non-null int64
query_on_thyroxine           3163 non-null int64
on_antithyroid_medication    3163 non-null int64
thyroid_surgery              3163 non-null int64
query_hypothyroid            3163 non-null int64
query_hyperthyroid           3163 non-null int64
pregnant                     3163 non-null int64
sick                         3163 non-null int64
tumor                        3163 non-null int64
lithium                      3163 non-null int64
goitre                       3163 non-null int64
TSH_measured                 3163 non-null int64
TSH                          2695 non-null float64
T3_measured                  3163 non-null int64
T3                           2468 non-null float64
TT4_measured                 3163 non-null int64
TT4                          2914 non-null float64
T4U_measured                 3163 non-null int64
T4U                          2915 non-null float64
FTI_measured                 3163 non-null int64
FTI                          2916 non-null float64
TBG_measured                 3163 non-null int64
dtypes: float64(6), int64(18)
```

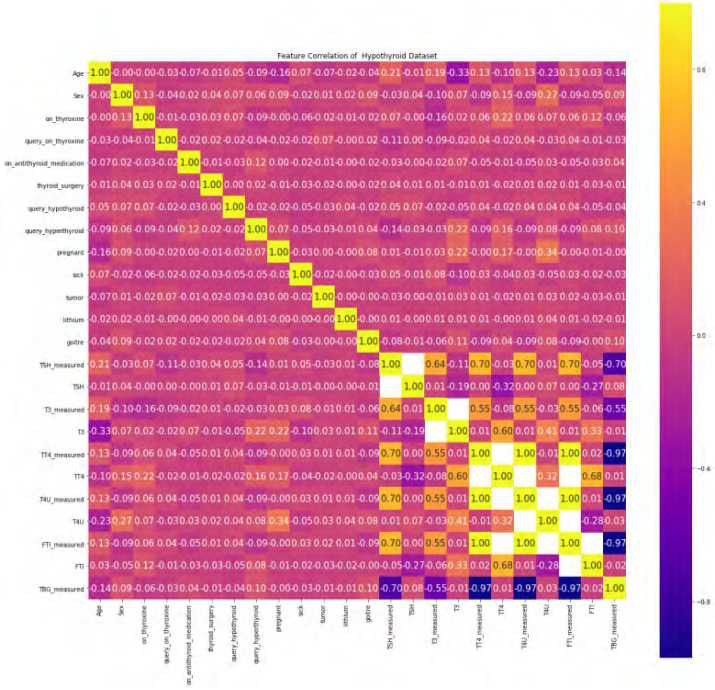

Figure 5. Statistical information and correlation matrix of the dataset.

Implementation was undertaken with Python under an NVidia Tesla V100 GPU server with 30 training epochs and a batch size of 64. All clinical parameters were analyzed by determining the relationship between each feature and its correlation, as shown in Figure 6.

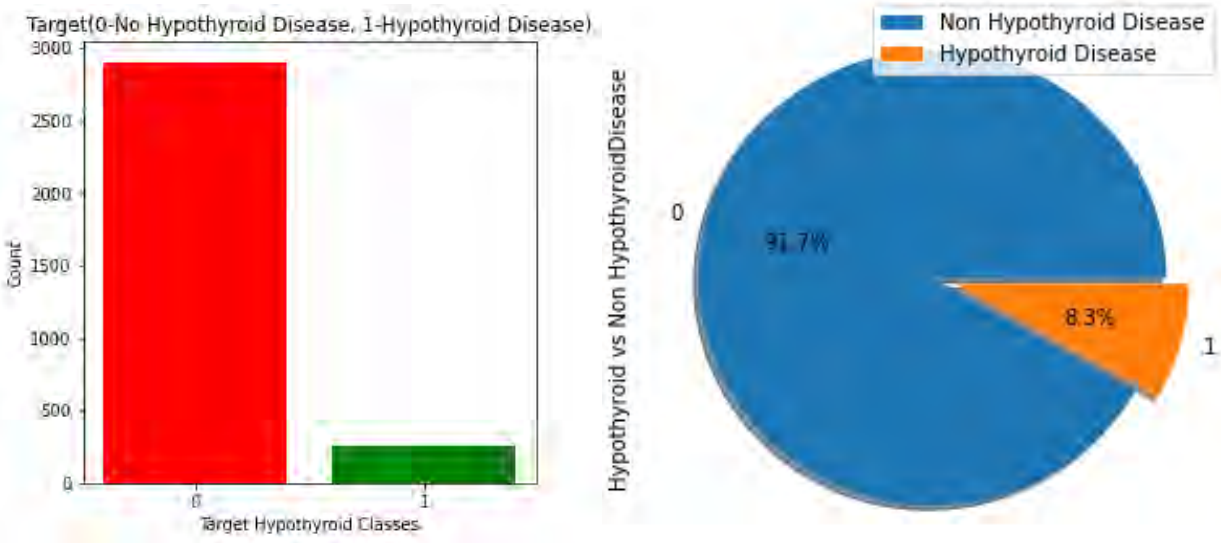

Figure 6. Density plot and target distribution of the hypothyroidism dataset.

4.1. Anova Test Analysis

ANOVA was carried out to analyze those attributes of the dataset with PR(>F) < 0.05 that highly influence the target. ANOVA was applied to the dataset features, and the results show that the features (thyroid surgery, pregnant, tumor, lithium) have values of PR(>F) > 0.05 and do not contribute to the target, the results are shown in Table 1.

Table 1. Attribute analysis with the ANOVA test.

Features	sum_sq	df	F-Statistic	PR(>F)
Age	4.105	1	55.1339	1.44×10^{-13}
Sex	2.127	1	28.3421	1.08×10^{-7}
on_thyroxine	0.920	1	12.1986	0.000485
query_on_thyroxine	0.238	1	3.1494	0.076051
on_antithyroid_medication	0.467	1	6.1798	0.012973
thyroid_surgery	0.024	1	0.3283	0.566654
query_hypothyroid	0.439	1	5.8059	0.016029
query_hyperthyroid	2.556	1	34.1124	5.72×10^{-9}
pregnant	0.006	1	0.0084	0.926861
sick	0.278	1	3.6821	0.052087
tumor	0.047	1	0.6241	0.429556
lithium	0.013	1	0.1798	0.6715
goitre	2.246	1	29.9307	4.82×10^{-8}
TSH_measured	117.418	1	3041.1975	0.000045
TSH	0.033	1	0.4446	0.050492
T3_measured	72.038	1	136.1074	5.89×10^{-248}
T3	0.008	1	0.0111	0.005934
TT4_measured	223.546	1	44,395.61	0.00043
TT4	0.00036	1	0.0047	0.00450
T4U_measured	224.534	1	47,542.78	0.00053
T4U	0.01087	1	0.14349	0.00485
FTI_measured	225.5303	1	51,167.19	0.00034
FTI	0.0036	1	0.0482	0.00049

4.2. Results and Discussion

Hypothyroidism was predicted using various classifier algorithms before and after feature scaling, the performances were analyzed, and the results are shown in Tables 2 and 3.

Table 2. Classification metrics before feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.834285	0.834261	0.834192	0.834261
KNeighbors classifier	0.840521	0.840521	0.840521	0.840521
Kernel SVM classifier	0.851174	0.922591	0.885445	0.922591
Gaussian naive Bayes	0.834285	0.834261	0.834192	0.834261
Decision tree classifier	0.846043	0.846101	0.846064	0.846101
Extra tree classifier	0.834285	0.834261	0.834192	0.834261
Random forest classifier	0.834285	0.834261	0.834192	0.834261
Gradient boosting classifier	0.846043	0.846101	0.846064	0.846101
AdaBoost classifier	0.84363	0.843681	0.84362	0.843681

Table 2. *Cont.*

Classifiers	Precision	Recall	FScore	Accuracy
Ridge classifier	0.834285	0.834261	0.834192	0.834261
Ridge classifierCV	0.834285	0.834261	0.834192	0.834261
SGD classifier	0.834285	0.834261	0.834192	0.834261

Table 3. Classification metrics after feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.847285	0.847261	0.847192	0.847261
KNeighbors classifier	0.846043	0.846101	0.846064	0.846101
Kernel SVM classifier	0.851174	0.922591	0.885445	0.922591
Gaussian baive Bayes	0.847285	0.847261	0.847192	0.847261
Decision tree classifier	0.834285	0.834261	0.834192	0.834261
Extra tree classifier	0.817655	0.817362	0.817477	0.817362
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.840521	0.840521	0.840521	0.840521
Ridge classifier	0.847285	0.847261	0.847192	0.847261
Ridge classifierCV	0.847285	0.847261	0.847192	0.847261
SGD classifier	0.847285	0.847261	0.847192	0.847261

The raw dataset was subjected to dimensionality reduction by using AdaBoost, gradient boosting regressor, extra trees, and random forest regressor feature-selection methods, and the feature importance values of each attribute of the hypothyroidism dataset before and after feature scaling are shown in Tables 4 and 5. The raw dataset was subjected to dimensionality reduction using AdaBoost, gradient boosting, extra trees, and random forest classifier feature-selection methods, and the feature importance values of each attribute of the hypothyroid dataset before and after scaling are shown in Tables 6 and 7.

Table 4. Regressor feature importance values of each feature before feature scaling.

Index	Classifiers	AdaBoost Regressor	Gradient Boosting Regressor	Extra Trees Regressor	Random Forest Regressor
0.	Age	0.000428341	0.003081406	0.010040952	0.007403365
1.	Sex	0.008622032	4.39×10^{-5}	0.002254928	0.000698556
2.	on_thyroxine	0	8.62×10^{-6}	0.000804381	0.000134897
3.	query_on_thyroxine	0	2.19×10^{-5}	0.000607023	0.00022945
4.	on_antithyroid_medication	0	0	0	0
5.	thyroid_surgery	0	0	1.29×10^{-5}	0
6.	query_hypothyroid	0	0	0.000137327	0
7.	query_hyperthyroid	0	0.000180298	0.001258513	0.00083488
8.	pregnant	0	1.03×10^{-20}	0	0
9.	sick	0	0	5.18×10^{-5}	0

Table 4. *Cont.*

Index	Classifiers	AdaBoost Regressor	Gradient Boosting Regressor	Extra Trees Regressor	Random Forest Regressor
10.	tumor	0	0	6.24×10^{-7}	0
11.	lithium	0	0	0	0
12.	goitre	0	1.87×10^{-5}	0.00336961	0.000819246
13.	TSH_measured	0.197501922	0.006246666	0.001243391	0.002119903
14.	TSH	0.077619094	0.001650685	0.002426862	0.002049851
15.	T3_measured	0.017306778	0.000365421	0.001073602	0.00051231
16.	T3	0	0.000614873	0.002119724	0.001266411
17.	TT4_measured	0.004126458	0	5.15×10^{-5}	0.056711358
18.	TT4	0.053174222	0.013884897	0.010358689	0.01558167
19.	T4U_measured	0	0	0	0.113416878
20.	T4U	0.080253371	0.007295723	0.01125785	0.011729611
21.	FTI_measured	0.505044774	0.957930603	0.943635215	0.774966334
22.	FTI	0.055923007	0.008656368	0.009295157	0.011525281

Table 5. Regressor Feature Importance Values of Each Features after Feature Scaling.

Features	AdaBoost	GradientBoosting	ExtraTrees	RandomForest
Age	0.018396825	0.003350051	0.010465358	0.007502654
Sex	0.006847598	4.39×10^{-5}	0.0022696	0.000651238
on_thyroxine	0	2.43×10^{-5}	0.000670722	0
query_on_thyroxine	0	2.19×10^{-5}	0.000453489	0.000176286
on_antithyroid_medication	0	0	0	0
thyroid_surgery	0	0	5.32×10^{-5}	0
query_hypothyroid	0	1.25×10^{-6}	0.000134226	0
query_hyperthyroid	0	0.000180298	0.001134248	0.00070627
pregnant	0	0	0	0
sick	0	0	7.78×10^{-5}	0
tumor	0	0	3.07×10^{-5}	0
lithium	0	0	0	0
goitre	0	1.87×10^{-5}	0.003884817	0.000984925
TSH_measured	0.130848738	0.005119183	0.00141153	0.002186828
TSH	0.140185147	0.000508619	0.002227775	0.002164946
T3_measured	0.016544939	0.001884564	0.001113277	0.000384264
T3	0.019546664	1.93×10^{-5}	0.001694519	0.000764557
TT4_measured	0.002640564	0	0	0.0375457
TT4	0.079190546	0.015118764	0.01054195	0.014953169
T4U_measured	0	0	0	0.170098636
T4U	0.131409566	0.007021985	0.010756814	0.012046173
FTI_measured	0.437162659	0.957930603	0.943635215	0.735679166
FTI	0.017226754	0.008756629	0.009444797	0.014155188

Table 6. Classifier feature importance values of each feature before feature scaling.

Features	AdaBoost	Gradient Boosting	Extra Trees	Random Forest
Age	0.3	0.00276237	0.010403875	0.009334997
Sex	0.04	6.31×10^{-5}	0.003167778	0.001804309
on_thyroxine	0.02	8.98×10^{-5}	0.002313404	0.001197477
query_on_thyroxine	0.02	9.65×10^{-6}	0.001441407	0.000280689
on_antithyroid_medication	0	-3.89×10^{-21}	0.000135951	3.81×10^{-5}
thyroid_surgery	0	0	0.000158409	9.99×10^{-5}
query_hypothyroid	0.02	4.13×10^{-20}	0.000274698	0.000158845
query_hyperthyroid	0.02	0.000142974	0.002732408	0.001816944
pregnant	0	1.67×10^{-21}	4.77×10^{-5}	0.000171466
sick	0	0	8.79×10^{-5}	4.88×10^{-5}
tumor	0	0	0.000788175	0.000713225
lithium	0	0	0	0
goitre	0	-1.70×10^{-18}	0.003266947	0.001503002
TSH_measured	0	0.002869076	0.077458279	0.048169136
TSH	0.1	0.001060964	0.003082501	0.046241881
T3_measured	0.04	0.000382842	0.032909932	0.05790805
T3	0.02	5.52×10^{-6}	0.003573637	0.004400236
TT4_measured	0	2.45×10^{-6}	0.224022987	0.16221615
TT4	0.16	0.011738893	0.013281768	0.050282253
T4U_measured	0	3.85×10^{-6}	0.25610996	0.301724198
T4U	0.12	0.008872811	0.013795367	0.045971388
FTI_measured	0.02	0.962267301	0.337492546	0.219637329
FTI	0.12	0.009728344	0.013454301	0.046281594

Table 7. Classifier feature importance values of each feature after feature scaling.

Features	AdaBoost	Gradient Boosting	Extra Trees	Random Forest
Age	0.3	0.002453486	0.009509937	0.008279074
Sex	0.04	4.82×10^{-5}	0.00324165	0.001846886
on_thyroxine	0.02	3.51×10^{-5}	0.00295889	0.000712379
query_on_thyroxine	0.02	7.33×10^{-6}	0.000800167	0.000653312
on_antithyroid_medication	0	0	0.000285502	0.000107717
thyroid_surgery	0	0	0.000100357	4.84×10^{-5}
query_hypothyroid	0.02	-3.89×10^{-21}	0.000245459	9.70×10^{-5}
query_hyperthyroid	0.02	0.000138031	0.002982702	0.001717612
pregnant	0	1.07×10^{-20}	4.60×10^{-5}	7.20×10^{-5}
sick	0	0	6.70×10^{-5}	4.23×10^{-6}
tumor	0	1.54×10^{-18}	0.00071482	0.000571423
lithium	0	0	0	0

Table 7. *Cont.*

Features	AdaBoost	Gradient Boosting	Extra Trees	Random Forest
goitre	0	-1.70×10^{-18}	0.002505062	0.000921635
TSH_measured	0	0.003078428	0.089211886	0.078112108
TSH	0.1	0.000978036	0.003674423	0.031291888
T3_measured	0.04	0.000575078	0.043737281	0.037562216
T3	0.02	9.39×10^{-6}	0.003354808	0.009181534
TT4_measured	0	7.58×10^{-6}	0.1820123	0.205768548
TT4	0.16	0.009939212	0.014136987	0.054038719
T4U_measured	0	0	0.355190855	0.242828144
T4U	0.12	0.008035637	0.013861521	0.035851905
FTI_measured	0.02	0.962709323	0.259146396	0.21946496
FTI	0.12	0.011985167	0.012216028	0.070868256

A feature importance index of all the regressor and classifier feature-selection methods of the hypothyroid dataset, before and after feature scaling, was also compared, and the results are shown in Table 8.

Table 8. Feature importance index of regressor and classifier methods.

Classifiers	Before Feature Scaling	After Feature Scaling
AdaBoost Regressor	13, 14, 18, 20, 21,22	0, 13, 14, 18, 20, 21
GradientBoostingRegressor	0, 13, 18, 20, 21, 22	0, 13, 18, 20, 21, 22
ExtraTrees Regressor	0, 12, 18, 20, 21, 22	0, 12, 18, 20, 21, 22
RandomForest Regressor	17, 18, 19, 20, 21, 22	17, 18, 19, 20, 21, 22
AdaBoost Classifier	0, 1, 14, 18, 20, 22	0, 1, 14, 18, 20, 22
GradientBoosting Classifier	0, 13, 18, 20, 21, 22	0, 13, 18, 20, 21, 22
ExtraTrees Classifier	13, 15, 17, 18, 19, 21	13, 15, 17, 18, 19, 21
RandomForest Classifier	13, 15, 17, 18, 19, 21	13, 15, 17, 18, 19, 21

The feature-selected subset of the AdaBoost regressor was applied to the classifiers, and the performance was analyzed. The results are shown in Tables 9 and 10.

Table 9. AdaBoost regressor metrics before feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.846043	0.846101	0.846064	0.846101
KNeighbors classifier	0.851174	0.822591	0.885445	0.822591
Kernel SVM classifier	0.847285	0.847261	0.847192	0.847261
Gaussian naive Bayes	0.895285	0.895261	0.895192	0.895261
Decision tree classifier	0.846043	0.846101	0.846064	0.846101
Extra tree classifier	0.851174	0.822591	0.885445	0.822591
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.895285	0.895261	0.895192	0.895261

Table 9. *Cont.*

Classifiers	Precision	Recall	FScore	Accuracy
Ridge classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifierCV	0.846043	0.846101	0.846064	0.846101
SGD classifier	0.834285	0.834261	0.834192	0.834261
Passive aggressive	0.846043	0.846101	0.846064	0.846101
Bagging classifier	0.834285	0.834261	0.834192	0.834261

Table 10. AdaBoost regressor metrics after feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.846043	0.846101	0.846064	0.846101
KNeighbors classifier	0.847285	0.847261	0.847192	0.847261
Kernel SVM classifier	0.834285	0.834261	0.834192	0.834261
Gaussian naive Bayes	0.895285	0.895261	0.895192	0.895261
Decision tree classifier	0.846043	0.846101	0.846064	0.846101
Extra tree classifier	0.851174	0.922591	0.885445	0.882591
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifierCV	0.834285	0.834261	0.834192	0.834261
SGD classifier	0.846043	0.846101	0.846064	0.846101
Passive aggressive	0.847285	0.847261	0.847192	0.847261
Bagging classifier	0.834285	0.834261	0.834192	0.834261

The feature-selected subset of the gradient boosting regressor was applied to the classifiers, the performances before and after feature scaling were analyzed, and the results are shown in Tables 11 and 12.

Table 11. Gradient boosting regressor metrics before feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.834285	0.834261	0.834192	0.834261
KNeighbors classifier	0.846043	0.846101	0.846064	0.846101
Kernel SVM classifier	0.847285	0.847261	0.847192	0.847261
Gaussian naive Bayes	0.895285	0.895261	0.895192	0.895261
Decision tree classifier	0.846043	0.846101	0.846064	0.846101
Extra tree classifier	0.851174	0.822591	0.885445	0.822591
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifier	0.895285	0.895261	0.895192	0.895261

Table 11. *Cont.*

Classifiers	Precision	Recall	FScore	Accuracy
Ridge classifierCV	0.834285	0.834261	0.834192	0.834261
SGD classifier	0.846043	0.846101	0.846064	0.846101
Passive aggressive classifier	0.847285	0.847261	0.847192	0.847261
Bagging classifier	0.834285	0.834261	0.834192	0.834261

Table 12. Gradient boosting regressor metrics after feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.847285	0.847261	0.847192	0.847261
KNeighbors classifier	0.847285	0.847261	0.847192	0.847261
Kernel SVM classifier	0.834285	0.834261	0.834192	0.834261
Gaussian naive Bayes	0.895285	0.895261	0.895192	0.895261
Decision tree	0.846043	0.846101	0.846064	0.846101
Extra tree classifier	0.851174	0.822591	0.885445	0.822591
Random forest classifier	0.847285	0.847261	0.847192	0.847261
GBoosting	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifierCV	0.834285	0.834261	0.834192	0.834261
SGD classifier	0.847285	0.847261	0.847192	0.847261
Passive Aggressive classifier	0.834285	0.834261	0.834192	0.834261
Bagging classifier	0.834285	0.834261	0.834192	0.834261

The feature-selected subset of extra trees regressor was applied to the classifiers, the performances before and after scaling were analyzed, and the results are shown in Tables 13 and 14.

Table 13. Extra trees regressor metrics before feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.834285	0.834261	0.834192	0.834261
KNeighbors classifier	0.846043	0.846101	0.846064	0.846101
Kernel SVM classifier	0.851174	0.822591	0.885445	0.822591
Gaussian naive Bayes	0.895285	0.895261	0.895192	0.895261
Decision tree classifier	0.847285	0.847261	0.847192	0.847261
Extra tree classifier	0.847285	0.847261	0.847192	0.847261
Random forest classifier	0.834285	0.834261	0.834192	0.834261
Gradient boosting classifier	0.847285	0.847261	0.847192	0.847261
AdaBoost classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifierCV	0.847285	0.847261	0.847192	0.847261

Table 13. *Cont.*

Classifiers	Precision	Recall	FScore	Accuracy
SGD classifier	0.834285	0.834261	0.834192	0.834261
Passive Aggressive classifier	0.847285	0.847261	0.847192	0.847261
Bagging classifier	0.834285	0.834261	0.834192	0.834261

Table 14. Extra trees regressor metrics after feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.846043	0.846101	0.846064	0.846101
KNeighbors classifier	0.851174	0.922591	0.885445	0.922591
Kernel SVM classifier	0.847285	0.847261	0.847192	0.847261
Gaussian naïve Bayes	0.895285	0.895261	0.895192	0.895261
Decision tree classifier	0.846043	0.846101	0.846064	0.846101
Extra tree classifier	0.851174	0.922591	0.885445	0.922591
Random Forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.846043	0.846101	0.846064	0.846101
AdaBoost classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifierCV	0.846043	0.846101	0.846064	0.846101
SGD classifier	0.851174	0.922591	0.885445	0.922591
Passive aggressive classifier	0.847285	0.847261	0.847192	0.847261
Bagging classifier	0.834285	0.834261	0.834192	0.834261

The feature-selected subset of random forest regressor was applied to the classifiers, the performances before and after feature scaling were analyzed, and the results are shown in Tables 15 and 16.

Table 15. Random forest regressor metrics before feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.847285	0.847261	0.847192	0.847261
KNeighbors classifier	0.834285	0.834261	0.834192	0.834261
Kernel SVM classifier	0.851174	0.922591	0.885445	0.922591
Gaussian naive Bayes	0.895285	0.895261	0.895192	0.895261
Decision tree classifier	0.847285	0.847261	0.847192	0.847261
Extra tree Classifier	0.834285	0.834261	0.834192	0.834261
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifierCV	0.834285	0.834261	0.834192	0.834261
SGD classifier	0.834285	0.834261	0.834192	0.834261
Passive aggressive classifier	0.847285	0.847261	0.847192	0.847261
Bagging classifier	0.834285	0.834261	0.834192	0.834261

Table 16. Random forest regressor metrics after feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.846043	0.846101	0.846064	0.846101
KNeighbors classifier	0.851174	0.822591	0.885445	0.822591
Kernel SVM classifier	0.847285	0.847261	0.847192	0.847261
Gaussian naive Bayes	0.895285	0.895261	0.895192	0.895261
Decision tree classifier	0.846043	0.846101	0.846064	0.846101
Extra tree classifier	0.851174	0.822591	0.885445	0.822591
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifier	0.895285	0.895261	0.895192	0.895261
Ridge classifierCV	0.847285	0.847261	0.847192	0.847261
SGD classifier	0.851174	0.822591	0.885445	0.822591
Passive aggressive classifier	0.847285	0.847261	0.847192	0.847261
Bagging classifier	0.834285	0.834261	0.834192	0.834261

The performances of all classifiers after reduction with the feature importance of the AdaBoost, gradient boost, extra tree, and random forest regressors before and after feature scaling are shown in Figures 7 and 8.

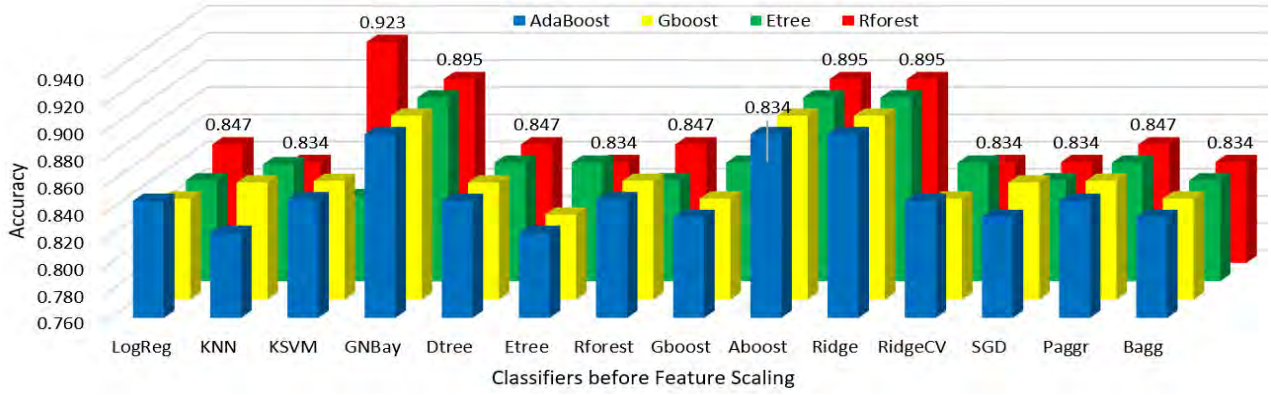

Figure 7. Regressor feature importance performance of all classifiers before scaling.

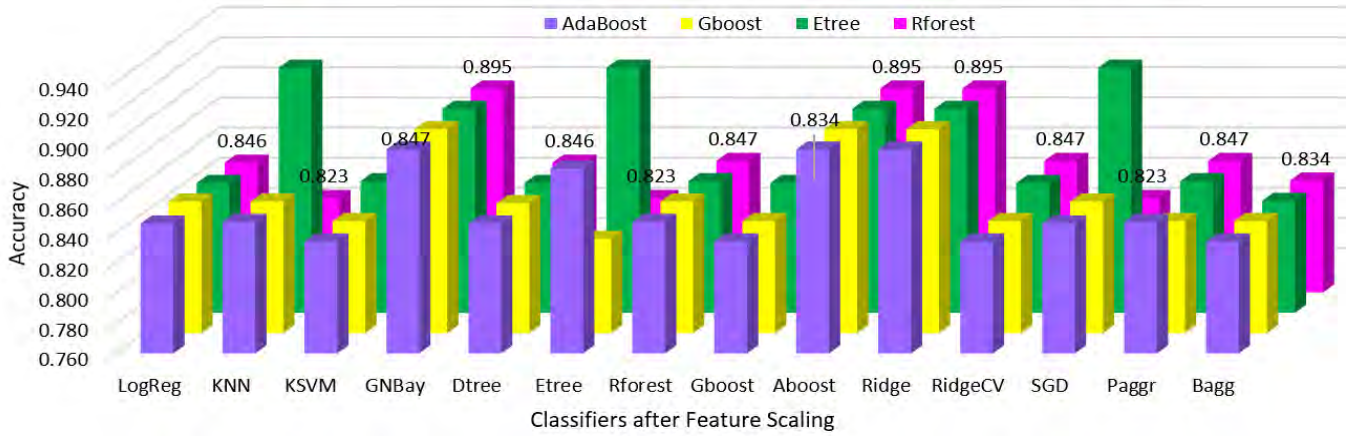

Figure 8. Regressor feature importance performance of all classifiers after scaling.

The feature selected subset of the AdaBoost classifier was applied to the other classifiers, the performances were analyzed, and the results are shown in Tables 17 and 18.

Table 17. AdaBoost classifier metrics before feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.851174	0.822591	0.885445	0.822591
KNeighbors classifier	0.875285	0.877261	0.877192	0.875261
Kernel SVM classifier	0.875285	0.877261	0.877192	0.875261
Gaussian naive Bayes	0.847285	0.847261	0.847192	0.847261
Decision tree classifier	0.851174	0.822591	0.885445	0.822591
Extra tree classifier	0.847285	0.847261	0.847192	0.847261
Random forest classifier	0.834285	0.834261	0.834192	0.834261
Gradient boosting classifier	0.851174	0.822591	0.885445	0.822591
AdaBoost classifier	0.847285	0.847261	0.847192	0.847261
Ridge classifier	0.875285	0.877261	0.877192	0.875261
Ridge classifierCV	0.834285	0.834261	0.834192	0.834261
SGD classifier	0.847285	0.847261	0.847192	0.847261
Passive aggressive classifier	0.834285	0.834261	0.834192	0.834261
Bagging classifier	0.851174	0.822591	0.885445	0.822591

Table 18. AdaBoost classifier metrics after feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.834285	0.834261	0.834192	0.834261
KNeighbors classifier	0.875285	0.877261	0.877192	0.875261
Kernel SVM classifier	0.875285	0.877261	0.877192	0.875261
Gaussian naive Bayes	0.834285	0.834261	0.834192	0.834261
Decision tree classifier	0.834285	0.834261	0.834192	0.834261
Extra tree classifier	0.847285	0.847261	0.847192	0.847261
Random forest classifier	0.834285	0.834261	0.834192	0.834261
Gradient boosting classifier	0.847285	0.847261	0.847192	0.847261
AdaBoost classifier	0.847285	0.847261	0.847192	0.847261
Ridge classifier	0.875285	0.877261	0.877192	0.875261
Ridge classifierCV	0.851174	0.822591	0.885445	0.822591
SGD classifier	0.834285	0.834261	0.834192	0.834261
Passive aggressive classifier	0.847285	0.847261	0.847192	0.847261
Bagging classifier	0.834285	0.834261	0.834192	0.834261

The feature-selected subset of the gradient boosting classifier was applied to the classifiers, the performances before and after feature scaling were analyzed, and the results are shown in Tables 19 and 20.

Table 19. Gradient boosting classifier metrics before feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.851174	0.822591	0.885445	0.822591
KNeighbors classifier	0.875285	0.877261	0.877192	0.875261
Kernel SVM classifier	0.875285	0.877261	0.877192	0.875261
Gaussian naive Bayes	0.847285	0.847261	0.847192	0.847261
Decision tree	0.834285	0.834261	0.834192	0.834261
Extra tree	0.847285	0.847261	0.847192	0.847261
Random forest	0.834285	0.834261	0.834192	0.834261
Gradient boosting	0.847285	0.847261	0.847192	0.847261
AdaBoost classifier	0.847285	0.847261	0.847192	0.847261
Ridge classifier	0.875285	0.877261	0.877192	0.875261
Ridge classifierCV	0.851174	0.922591	0.885445	0.922591
SGD classifier	0.847285	0.847261	0.847192	0.847261
Passive aggressive classifier	0.834285	0.834261	0.834192	0.834261
Bagging classifier	0.847285	0.847261	0.847192	0.847261

Table 20. Gradient boosting classifier metrics after feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.834285	0.834261	0.834192	0.834261
KNeighbors classifier	0.875285	0.877261	0.877192	0.875261
Kernel SVM classifier	0.875285	0.877261	0.877192	0.875261
Gaussian naive Bayes	0.834285	0.834261	0.834192	0.834261
Decision tree classifier	0.851174	0.822591	0.885445	0.822591
Extra tree classifier	0.834285	0.834261	0.834192	0.834261
Random forest classifier	0.851174	0.822591	0.885445	0.822591
Gradient boosting classifier	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.834285	0.834261	0.834192	0.834261
Ridge classifier	0.875285	0.877261	0.877192	0.875261
Ridge classifierCV	0.851174	0.922591	0.885445	0.922591
SGD classifier	0.851174	0.822591	0.885445	0.822591
Passive aggressive classifier	0.854541	0.895735	0.87404	0.895735
Bagging classifier	0.834285	0.834261	0.834192	0.834261

The feature selected subset of the extra trees classifier was applied to the other classifiers, the performances were analyzed, and the results are shown in Tables 21 and 22.

Table 21. Extra trees classifier metrics before feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.834285	0.834261	0.834192	0.834261
KNeighbors classifier	0.875285	0.877261	0.877192	0.875261
Kernel SVM classifier	0.875285	0.877261	0.877192	0.875261

Table 21. *Cont.*

Classifiers	Precision	Recall	FScore	Accuracy
Gaussian naive Bayes	0.834285	0.834261	0.834192	0.834261
Decision tree classifier	0.834285	0.834261	0.834192	0.834261
Extra tree classifier	0.851174	0.822591	0.885445	0.822591
Random forest classifier	0.834285	0.834261	0.834192	0.834261
Gradient boosting classifier	0.851174	0.822591	0.885445	0.822591
AdaBoost classifier	0.834285	0.834261	0.834192	0.834261
Ridge classifier	0.875285	0.877261	0.877192	0.875261
Ridge classifierCV	0.834285	0.834261	0.834192	0.834261
SGD classifier	0.851174	0.822591	0.885445	0.822591
Passive aggressive	0.834285	0.834261	0.834192	0.834261
Bagging classifier	0.847285	0.847261	0.847192	0.847261

Table 22. Extra trees classifier metrics after feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.834285	0.834261	0.834192	0.834261
KNeighbors classifier	0.875285	0.877261	0.877192	0.875261
Kernel SVM classifier	0.875285	0.877261	0.877192	0.875261
Gaussian naive Bayes	0.897285	0.897261	0.897192	0.897261
Decision Tree classifier	0.851174	0.822591	0.885445	0.822591
Extra tree classifier	0.834285	0.834261	0.834192	0.834261
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.834285	0.834261	0.834192	0.834261
Ridge classifier	0.875285	0.877261	0.877192	0.875261
Ridge classifierCV	0.851174	0.822591	0.885445	0.822591
SGD classifier	0.834285	0.834261	0.834192	0.834261
Passive aggressive classifier	0.851174	0.822591	0.885445	0.822591
Bagging classifier	0.834285	0.834261	0.834192	0.834261

The feature-selected subset of the random forest classifier was applied to the other classifiers, the performances before and after feature scaling were analyzed, and the results are shown in Tables 23 and 24.

Table 23. Random forest classifier metrics before feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.851174	0.822591	0.885445	0.822591
KNeighbors classifier	0.875285	0.877261	0.877192	0.875261
Kernel SVM classifier	0.875285	0.877261	0.877192	0.875261
Gaussian naive Bayes	0.897285	0.897261	0.897192	0.897261
Decision tree classifier	0.851174	0.822591	0.885445	0.822591

Table 23. *Cont.*

Classifiers	Precision	Recall	FScore	Accuracy
Extra tree classifier	0.834285	0.834261	0.834192	0.834261
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.831174	0.832591	0.835445	0.832591
AdaBoost classifier	0.834285	0.834261	0.834192	0.834261
Ridge classifier	0.875285	0.877261	0.877192	0.875261
Ridge classifierCV	0.834285	0.834261	0.834192	0.834261
SGD classifier	0.847285	0.847261	0.847192	0.847261
Passive aggressive classifier	0.831174	0.832591	0.835445	0.832591
Bagging classifier	0.847285	0.847261	0.847192	0.847261

Table 24. Random forest classifier metrics after feature scaling.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.847285	0.847261	0.847192	0.847261
KNeighbors classifier	0.875285	0.877261	0.877192	0.875261
Kernel SVM classifier	0.875285	0.877261	0.877192	0.875261
Gaussian naive Bayes	0.834285	0.834261	0.834192	0.834261
Decision tree classifier	0.851174	0.822591	0.885445	0.822591
Extra tree classifier	0.834285	0.834261	0.834192	0.834261
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting classifier	0.831174	0.832591	0.835445	0.832591
AdaBoost classifier	0.834285	0.834261	0.834192	0.834261
Ridge classifier	0.875285	0.877261	0.877192	0.875261
Ridge classifierCV	0.851174	0.822591	0.885445	0.822591
SGD classifier	0.834285	0.834261	0.834192	0.834261
Passive aggressive	0.847285	0.847261	0.847192	0.847261
Bagging classifier	0.831174	0.832591	0.835445	0.832591

The performances of all classifiers after reduction with the feature importance of the AdaBoost, gradient boost, extra tree, and random forest classifiers before and after feature scaling are shown in Figures 9 and 10.

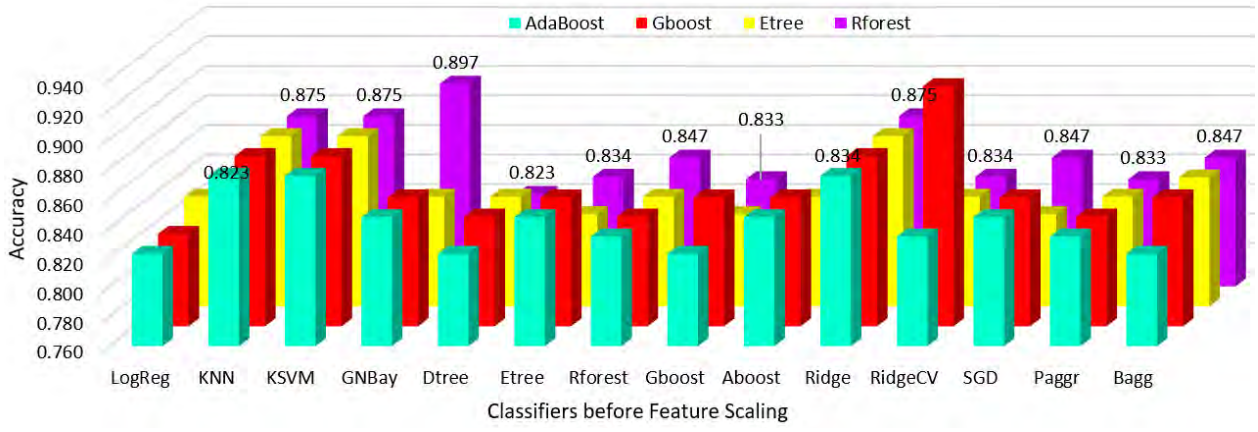

Figure 9. Classifier feature importance performance of all classifiers before scaling.

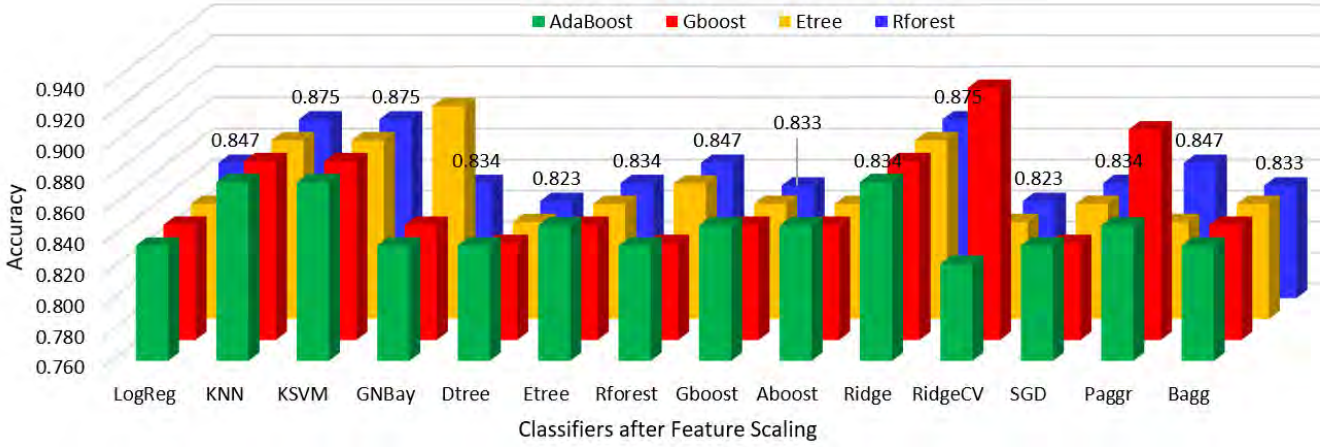

Figure 10. Classifier feature importance performance of all classifiers after scaling.

The overall dataset was analyzed with the OLS features, such as *p* value, R squared, adjusted R squared, parameter coefficient, significance, AIC, BIC, standard error, F-statistic, log-likelihood, residual MSE, model MSE, omnibus probability, and JarqueBera probability for all 255 subset combinations of the features. The following subset includes highly significant features based on the *p* values, and the parameters are listed in Tables 25–28.

Table 25. OLS features of the significant subset attributes of the hypothyroidism dataset.

S.No	Attributes	R Squared	Adjusted R Squared	Parameter Coefficient
1.	['TSH_measured']	0.490342	0.490181	[−0.1926723]
2.	['TSH_measured' 'TSH' 'TT4_measured']	0.934966	0.934904	[−0.01378328 0.00334404 −0.25622659]
3.	['TSH_measured' 'TSH' 'T4U_measured']	0.939086	0.939028	[−0.01372514 0.00334439 −0.25687507]
4.	['TSH_measured' 'T3_measured']	0.508019	0.507707	[−0.16245081 −0.04745117]
5.	['TSH_measured' 'T3_measured' 'T3']	0.508773	0.508306	[−0.16300138 −0.04710052 −0.00756629]
6.	['TSH_measured' 'T3']	0.491378	0.491056	[−0.19305575 −0.00886611]
7.	['TSH_measured' 'T3' 'T4U']	0.492164	0.491682	[−0.19327524 −0.01212442 0.00837232]
8.	['TSH_measured' 'TT4_measured']	0.934818	0.934777	[−0.01378472 −0.25622453]
9.	['TSH_measured' 'T4U_measured']	0.938938	0.9389	[−0.01372657 −0.25687302]
10.	['TSH' 'T3_measured' 'TT4_measured']	0.934199	0.934136	[0.00338423 −0.00749316 −0.26174326]
11.	['TSH' 'T3_measured' 'T4U_measured']	0.938323	0.938265	[0.0033845 −0.00747897 −0.26234687]
12.	['TSH' 'TT4_measured']	0.93368	0.933638	[0.00334707 −0.26584963]
13.	['TSH' 'T4U_measured']	0.937806	0.937766	[0.00334741 −0.26643643]
14.	['T3_measured']	0.300835	0.300614	[−0.15091554]
15.	['T3_measured' 'TT4_measured']	0.934047	0.934006	[−0.00746918 −0.26175534]
16.	['T3_measured' 'TT4']	0.302135	0.301694	[−0.15159006 −0.00994458]
17.	['T3_measured' 'T4U_measured']	0.938172	0.938133	[−0.00745503 −0.26235889]
18.	['TT4_measured']	0.933532	0.933511	[−0.26584857]
19.	['T4U_measured']	0.937658	0.937638	[−0.26643537]

Table 26. OLS features of the significant subset attributes of the hypothyroid dataset.

S.No	Attributes	*p* Values	AIC	BIC
1.	['TSH_measured']	[0.]	−1315.02	−1302.9
2.	['TSH_measured' 'TSH' 'TT4_measured']	[$3.69199042 \times 10^{-15}$ $7.43156772 \times 10^{-3}$ 0.00000000]	−7823.1	−7798.86
3.	['TSH_measured' 'TSH' 'T4U_measured']	[$5.19971275 \times 10^{-16}$ $5.67318032 \times 10^{-3}$ 0.00000000]	−8030.12	−8005.88
4.	['TSH_measured' 'T3_measured']	[$1.81373646 \times 10^{-243}$ $4.53106996 \times 10^{-26}$]	−1424.67	−1406.49
5.	['TSH_measured' 'T3_measured' 'T3']	[$1.93109194 \times 10^{-244}$ $1.02662783 \times 10^{-25}$ $2.77571221 \times 10^{-2}$]	−1427.52	−1403.28
6.	['TSH_measured' 'T3']	[0. 0.01121299]	−1319.46	−1301.28
7.	['TSH_measured' 'T3' 'T4U']	[0. 0.00139307 0.02711176]	−1322.35	−1298.11
8.	['TSH_measured' 'TT4_measured']	[$3.89722887 \times 10^{-15}$ 0.00000000]	−7817.92	−7799.74
9.	['TSH_measured' 'T4U_measured']	[$5.53480256 \times 10^{-16}$ 0.00000000]	−8024.46	−8006.28
10.	['TSH' 'T3_measured' 'TT4_measured']	[$7.07863933 \times 10^{-3}$ $6.32943158 \times 10^{-7}$ 0.00000000]	−7786	−7761.76
11.	['TSH' 'T3_measured' 'T4U_measured']	[$5.40529071 \times 10^{-3}$ $2.75925083 \times 10^{-7}$ 0.00000000]	−7990.75	−7966.52
12.	['TSH' 'TT4_measured']	[0.00796318 0.]	−7763.15	−7744.97
13.	['TSH' 'T4U_measured']	[0.00613635 0.]	−7966.31	−7948.13
14.	['T3_measured']	[$5.89765862 \times 10^{-248}$]	−315.046	−302.927
15.	['T3_measured' 'TT4_measured']	[$7.04200951 \times 10^{-7}$ 0.00000000]	−7780.73	−7762.56
16.	['T3_measured' 'TT4']	[$3.72603592 \times 10^{-249}$ $1.53025228 \times 10^{-2}$]	−318.934	−300.756
17.	['T3_measured' 'T4U_measured']	[$3.09674931 \times 10^{-7}$ 0.00000000]	−7985	−7966.83
18.	['TT4_measured']	[0.]	−7758.1	−7745.98
19.	['T4U_measured']	[0.]	−7960.79	−7948.67

Table 27. OLS features of the significant subset attributes of the hypothyroid dataset.

S.No	Attributes	StandardError	FStatistic	Likelihood
1.	['TSH_measured']	[0.00349379]	3041.198	659.5089
2.	['TSH_measured' 'TSH' 'TT4_measured']	[0.00174378 0.00124843 0.00174378]	15,138.54	3915.549
3.	['TSH_measured' 'TSH' 'T4U_measured']	[0.00168412 0.00120824 0.00168412]	16,233.73	4019.059
4.	['TSH_measured' 'T3_measured']	[0.00445323 0.00445323]	1631.505	715.3352
5.	['TSH_measured' 'T3_measured' 'T3']	[0.00445754 0.00445337 0.00343653]	1090.61	717.7602
6.	['TSH_measured' 'T3']	[0.00349406 0.00349406]	1526.435	662.7281
7.	['TSH_measured' 'T3' 'T4U']	[0.00349332 0.00379016 0.00378678]	1020.505	665.1734
8.	['TSH_measured' 'TT4_measured']	[0.00174548 0.00174548]	22,659.94	3911.961
9.	['TSH_measured' 'T4U_measured']	[0.0016859 0.0016859]	24,295.55	4015.228

Table 27. *Cont.*

S.No	Attributes	StandardError	FStatistic	Likelihood
10.	['TSH' 'T3_measured' 'TT4_measured']	[0.0012558 0.00150131 0.00150129]	14,949.73	3896.998
11.	['TSH' 'T3_measured' 'T4U_measured']	[0.0012158 0.00145213 0.00145211]	16,019.93	3999.377
12.	['TSH' 'TT4_measured']	[0.00126052 0.00126052]	22,243.82	3884.576
13.	['TSH' 'T4U_measured']	[0.00122068 0.00122068]	23,824.18	3986.153
14.	['T3_measured']	[0.00409211]	1360.107	159.5229
15.	['T3_measured' 'TT4_measured']	[0.00150277 0.00150277]	22,376.61	3893.367
16.	['T3_measured' 'TT4']	[0.00409839 0.00409839]	684.0491	162.4668
17.	['T3_measured' 'T4U_measured']	[0.00145365 0.00145365]	23,974.81	3995.502
18.	['TT4_measured']	[0.00126172]	44,395.61	3881.051
19.	['T4U_measured']	[0.00122194]	47,542.78	3982.394

Table 28. OLS features of the significant subset attributes of the hypothyroid dataset.

S.No	Attributes	Residual MSE	Model MSE	Omnibus Probability	JarqueBera Probability
1.	['TSH_measured']	0.038609	0.075732	2.61×10^{-76}	0
2.	['TSH_measured' 'TSH' 'TT4_measured']	0.00493	0.075732	0	0
3.	['TSH_measured' 'TSH' 'T4U_measured']	0.004617	0.075732	0	0
4.	['TSH_measured' 'T3_measured']	0.037282	0.075732	2.49×10^{-75}	0
5.	['TSH_measured' 'T3_measured' 'T3']	0.037237	0.075732	1.90×10^{-75}	0
6.	['TSH_measured' 'T3']	0.038543	0.075732	4.64×10^{-76}	0
7.	['TSH_measured' 'T3' 'T4U']	0.038496	0.075732	7.40×10^{-76}	0
8.	['TSH_measured' 'TT4_measured']	0.004939	0.075732	0	0
9.	['TSH_measured' 'T4U_measured']	0.004627	0.075732	0	0
10.	['TSH' 'T3_measured' 'TT4_measured']	0.004988	0.075732	0	0
11.	['TSH' 'T3_measured' 'T4U_measured']	0.004675	0.075732	0	0
12.	['TSH' 'TT4_measured']	0.005026	0.075732	0	0
13.	['TSH' 'T4U_measured']	0.004713	0.075732	0	0
14.	['T3_measured']	0.052966	0.075732	0	0
15.	['T3_measured' 'TT4_measured']	0.004998	0.075732	0	0
16.	['T3_measured' 'TT4']	0.052884	0.075732	0	0
17.	['T3_measured' 'T4U_measured']	0.004685	0.075732	0	0
18.	['TT4_measured']	0.005035	0.075732	0	0
19.	['T4U_measured']	0.004723	0.075732	0	0

Experimental results show that the Gaussian naive Bayes, AdaBoost classifier, and Ridge classifier maintained an accuracy of 89.5% before and after feature scaling for the regressor feature-selection methods. The proposed BCRM was designed with Gaussian naïve Bayes, Ada boost, and Ridge as the estimators and with accuracy optimization using soft blending based on the sum of predicted probabilities of classifiers. The proposed BCRM model showed 99.5% accuracy in predicting hypothyroidism. The implementation

results show that the Kernel SVM, KNeighbor, and Ridge classifiers maintained an accuracy of 87.5% before and after feature scaling for the classifier feature-selection methods. The BCCM was created with Kernel SVM, KNeighbor, and Ridge as the estimators with accuracy optimization using soft blending based on the sum of the predicted probabilities of classifiers. The proposed BCCM showed 99.7% accuracy in predicting hypothyroidism. The performance analysis of the proposed BCRM was analyzed with the existing classifiers and the results are shown in Table 29 and Figure 11.

Table 29. Performance analysis of proposed BCRM and BCCM with existing classifiers.

Classifiers	Precision	Recall	FScore	Accuracy
Logistic regression	0.847285	0.847261	0.847192	0.847261
KNeighbors classifier	0.846043	0.846101	0.846064	0.846101
Kernel SVM classifier	0.851174	0.922591	0.885445	0.922591
Gaussian naive Bayes	0.847285	0.847261	0.847192	0.847261
Decision tree classifier	0.834285	0.834261	0.834192	0.834261
Extra tree classifier	0.817655	0.817362	0.817477	0.817362
Random forest classifier	0.847285	0.847261	0.847192	0.847261
Gradient boosting	0.834285	0.834261	0.834192	0.834261
AdaBoost classifier	0.840521	0.840521	0.840521	0.840521
Ridge classifier	0.847285	0.847261	0.847192	0.847261
Ridge classifierCV	0.847285	0.847261	0.847192	0.847261
SGD classifier	0.847285	0.847261	0.847192	0.847261
Proposed BCRM	0.995234	0.995224	0.995334	0.995334
Proposed BCCM	0.997432	0.997422	0.997432	0.997454

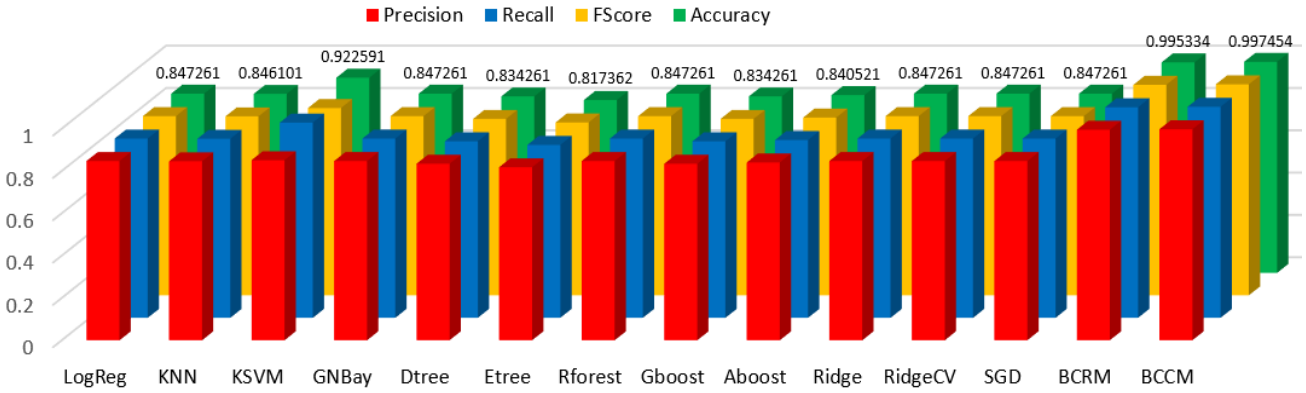

Figure 11. Performance of Proposed BCRM and BCCM with existing classifiers.

5. Conclusions

This paper aimed to predict the existence of hypothyroidism based on an analysis of the features required for classification. The ANOVA test was utilized for the identification of the significant features that predict the target variable. This paper also attempted to apply the regressor and classifier feature-selection algorithms to reduce the dataset with significant features. The dataset was also examined with OLS performance indicators for identification of the best subset of features based on p values. The subset feature ['TSH_measured', 'T4U_measured'] has an R squared value of 0.938, which is close to the ideal value. The implementation was carried out with Python in Spyder editor with the Anaconda Navigator IDE. Experimental results show that the Gaussian naive Bayes, AdaBoost classifier, and Ridge classifier maintained an accuracy of 89.5% before and after

feature scaling for the regressor feature-selection methods. The MCRM was developed with Gaussian naive Bayes, Ada boost, and Ridge as the estimators, with accuracy optimization using soft blending based on the sum of predicted probabilities of classifiers. The proposed BCRM showed 99.5% accuracy in predicting hypothyroidism. The implementation results show that the Kernel SVM, KNeighbor, and Ridge classifiers maintained an accuracy of 87.5% before and after feature scaling for the classifier feature selection methods. The blunge calibration classifier model was developed with Kernel SVM, KNeighbor, and Ridge as the estimators, with accuracy optimization using soft blending based on the sum of predicted probabilities of classifiers. The proposed blunge calibration classifier model showed 99.7% accuracy in predicting hypothyroidism. As an overview of novelty, the BCCM and BCRM models were built to optimize accuracy with soft blending based on the sum of predicted probabilities of classifiers. The BCRM and BCCM models uniqueness's are achieved by updating the estimators list with the effective classifiers and regressors that suit the application at runtime. Despite the outstanding performance of the BCRM and BCCM models, it is still difficult for researchers to adjust the model hyper-parameters by combining them with other optimizers and statistical loss functions.

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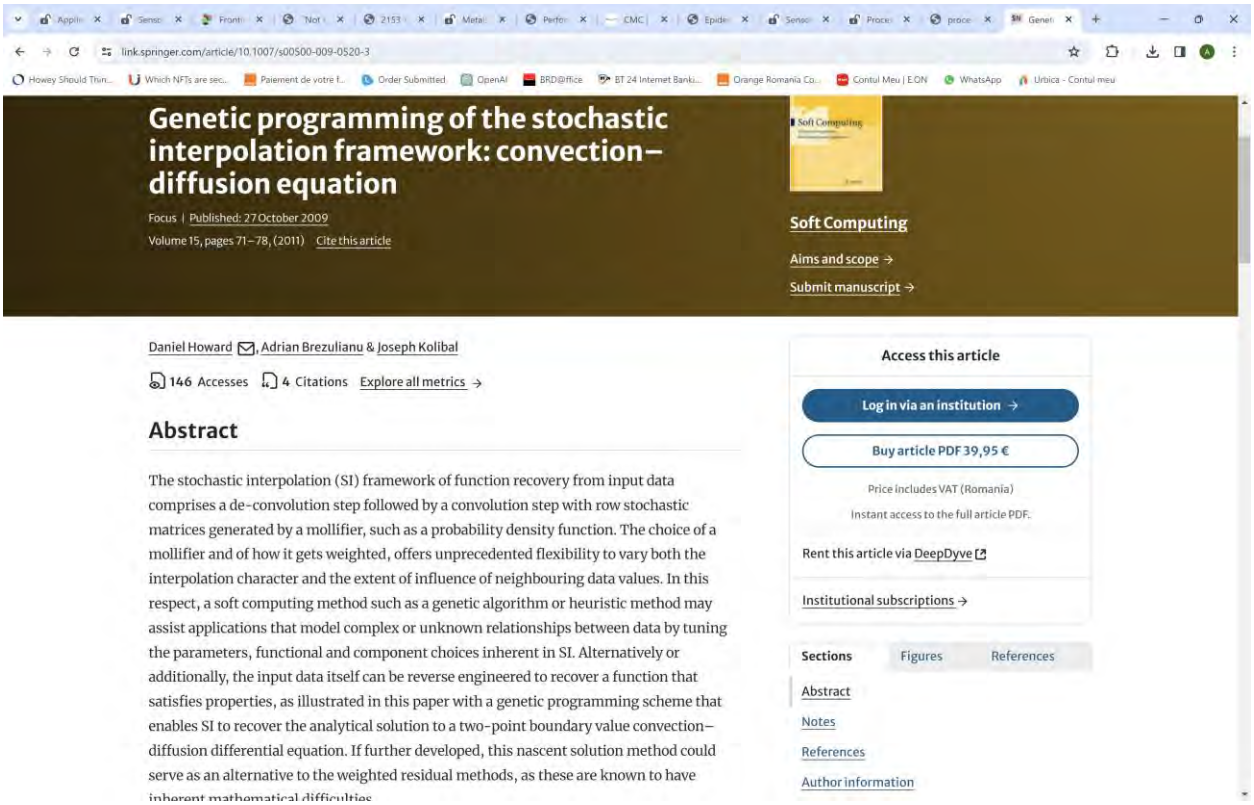
References

1. Marimuthu, M.; Hariesh, K.; Madhankumar, K. Heart Disease Prediction using Machine Learning and Data Analytics Approach. *Int. J. Comput. Appl.* **2018**, *181*, 20–25. [CrossRef]
2. Huang, Q.-A.; Dong, L.; Wang, L.-F. Cardiotocography Analysis for Fetal State Classification Using Machine Learning Algorithms. *J. Micro Electromech. Syst.* **2016**, *25*.
3. Maknouninejad, A.; Woronowicz, K.; Safaee, A. Enhanced Algorithm for Real Time Temperature Rise Prediction of A Traction Linear Induction Motor. In Proceedings of the 2018 IEEE Transportation Electrification Conference and Expo (ITEC), Long Beach, CA, USA, 13–15 June 2018.
4. Lakshmanaprabu, S.K.; Shankar, K.; Khanna, A.; Gupta, D.; Rodrigues, J.J.P.C.; Pinheiro, P.R.; De Albuquerque, V.H.C. Effective Features to Classify Big Data Using Social Internet of Things. *IEEE Access* **2018**, *6*, 24196–24204. [CrossRef]
5. Jancovic, P.; Kokuer, M. Bird Species Recognition Using Unsupervised Modeling of Individual Vocalization Elements. *IEEE/ACM Trans. Audio Speech Lang. Process.* **2019**, *27*, 932–947. [CrossRef]
6. Sethi, P.; Jain, M. Comparative Feature Selection Approach for the Prediction of Healthcare Coverage. *Commun. Comput. Inf. Sci.* **2010**, *54*, 392–403.
7. Piri, J.; Mohapatra, P.; Dey, R. Fetal Health Status Classification Using MOGA—CD Based Feature Selection Approach. In Proceedings of the IEEE International Conference on Electronics, Computing and Communication Technologies, Bangalore, India, 2–4 July 2020.
8. Keenan, E.; Udhayakumar, R.; Karmakar, C.; Brownfoot, F.; Palaniswami, M. Entropy Profiling for Detection of Fetal Arrhythmias in Short Length Fetal Heart Rate Recordings. In Proceedings of the International Conference of the IEEE Engineering in Medicine & Biology Society, Montreal, QC, Canada, 20–24 July 2020.
9. Li, J.; Huang, L.; Shen, Z.; Zhang, Y.; Fang, M.; Li, B.; Fu, X.; Zhao, Q.; Wang, H. Automatic Classification of Fetal Heart Rate Based on Convolutional Neural Network. *IEEE Internet Things J.* **2019**, *6*, 1394–1401. [CrossRef]
10. Chen, M.; Hao, Y.; Hwang, K.; Wang, L. Disease prediction by machine learning over big data from health care communities. *IEEE Access* **2017**, *5*, 8869–8879. [CrossRef]

11. Dahiwade, D.; Patle, G.; Meshram, E. Designing disease prediction model using machine learning approach. In Proceedings of the 3rd International Conference on Computing Methodologies and Communication (ICCMC) (Erode, 2019), Erode, India, 27–29 March 2019; pp. 1211–1215.
12. Razia, S.; Rao, M. Machine Learning Techniques for Thyroid Disease Diagnosis—A Review. *Indian J. Sci. Technol.* **2016**, *9*, 28. [CrossRef]
13. Tyagi, A.; Mehra, R.; Saxena, A. Interactive Thyroid Disease Prediction System Using Machine Learning Technique. In Proceedings of the IEEE International Conference on Parallel, Distributed and Grid Computing (PDGC-2018), Solan, India, 20–22 December 2018; pp. 20–22.
14. Liu, D.Y.; Chen, H.L.; Yang, B.L.; Lv, X.-E.; Li, L.-N.; Liu, J. Design of an Enhanced Fuzzy k-nearest Neighbor Classifier Based Computer Aided Diagnostic System for Thyroid Disease. *J. Med. Syst.* **2011**, *36*, 3243–3254. [CrossRef]
15. Shankar KLakshmanaprabu, S.K.; Gupta, D. Optimal feature-based multi-kernel SVM approach for thyroid disease classification. *J. Supercomput.* **2020**, *76*, 1128–1143. [CrossRef]
16. Cheng, C.A.; Lin, Y.; Chiu, H.W. Prediction of the prognosis of ischemic stroke patients after intravenous thrombolysis using artificial neural networks. *Stud. Health Technol. Inform.* **2014**, *202*, 115–118.
17. Ntaios, G.; Faouzi, M.; Ferrari, W.; Lang, J.; Vemmos, K.; Michel, P. An integer-based score to predict functional outcome in acute ischemic stroke: The ASTRAL score. *Neurology* **2012**, *78*, 1916–1922. [CrossRef]
18. Subudhi, A.; Dash, M.; Sabut, S. Automated segmentation and classification of brain stroke using expectation-maximization and random forest classifier. Biocybern. *Biomed. Eng.* **2020**, *40*, 277–289.
19. Jardine, A.K.S.; Lin, D.; Banjevic, D. A review on machinery diagnostics and prognostics implementing condition-based maintenance. *Mech. Syst. Signal Process.* **2006**, *20*, 1483–1510. [CrossRef]
20. Lee, H.J.; Lee, J.; Choi, J.; Cho, Y.; Kim, B.; Bae, H.; Kim, D.; Ryu, W.; Cha, J.; Kim, D. Simple estimates of symptomatic intracranial hemorrhage risk and outcome after intravenous thrombolysis using age and stroke severity. *J. Stroke* **2017**, *19*, 229–231. [CrossRef]
21. Dogan, S.; Barua, P.D.; Baygin, M.; Chakraborty, S.; Ciaccio, E.; Tuncer, T.; Kadir, K.A.; Shah, M.N.M.; Azman, R.R.; Lee, C.; et al. Novel multiple pooling and local phase quantization stable feature extraction techniques for automated classification of brain infarcts. *Biocybern. Biomed. Eng.* **2022**, *42*, 888–901. [CrossRef]
22. Alsobhi, A.Y.; Khan, N.; Rahanu, H. Personalised learning materials based on dyslexia types: Ontological approach. *Proc. Comput. Sci.* **2015**, *60*, 113–121. [CrossRef]
23. Al-Barhamtoshy, H.M.; Motaweh, D.M. Diagnosis of dyslexia using computation analysis. In Proceedings of the 2017 International Conference on Informatics, Health & Technology (ICIHT), Riyadh, Saudi Arabia, 21–23 February 2017; pp. 1–7.
24. Rauschenberger, M.; Rello, L.; Baeza-Yates, R.; Bigham, J.P. Towards language independent detection of dyslexia with a web-basedgame. In Proceedings of the 15th International Web for All Conference, Lyon, France, 23–25 April 2018; pp. 1–10.
25. Frid, A.; Manevitz, L.M. Features and machine learning for correlating and classifying between brain areas and dyslexia. *arXiv* **2018**, arXiv:1812.10622.
26. Perera, H.; Shiratuddin, M.F.; Wong, K.W.; Fullarton, K. Eeg signal analysis of writing and typing between adults with dyslexia and normal controls. *Int. J. Interact. Multimed. Artif. Intell.* **2018**, *5*, 62. [CrossRef]
27. Oliver, E.C.J.; Wotherspoon, S.J.; Chamberlain, M.A.; Holbrook, N.J. Projected Tasman Sea extremes in sea surface temperature through the twenty-first century. *J. Clim.* **2014**, *27*, 1980–1998. [CrossRef]
28. Gopi, K.; Mazumder, D.; Sammut, J.; Saintilan, N.; Crawford, J.; Gadd, P. Isotopic and elemental profiling to trace the geographic origins of farmed and wild-caught Asian seabass. *Aquaculture* **2019**, *502*, 56–62. [CrossRef]
29. Yucemen, M.S.; Askan, A. Estimation of Earthquake Damage Probabilities for Reinforced Concrete Buildings. In *Seismic Assessment and Rehabilitation of Existing Buildings*; NATO Science Series; Springer: Berlin/Heidelberg, Germany, 2003; Volume 29, pp. 149–164.
30. Zheng, X.-W.; Li, H.-N.; Yang, Y.-B.; Li, G.; Huo, L.-S.; Liu, Y. Damage risk assessment of a high-rise building against multihazard of earthquake and strong wind with recorded data. *Eng. Struct.* **2019**, *200*, 1096971. [CrossRef]
31. Nai-arun, N.; Moungmai, R. Comparison of Classifiers for the Risk of Diabetes Prediction. *Procedia Comput. Sci.* **2015**, *69*, 132–142. [CrossRef]
32. Swapna, G.; Soman, K.P.; Vinayakumar, R. Automated detection of diabetes using CNN and CNN-LSTM network and heart rate signals. *Procedia Comput. Sci.* **2018**, *132*, 1253–1262.
33. Mujumdara, A.; Vaidehi, V. Diabetes Prediction using Machine Learning Algorithm. *Procedia Comput. Sci.* **2019**, *165*, 292–299. [CrossRef]
34. Refat, M.A.; Al Amin, M.; Kaushal, C.; Yeasmin, M.N.; Islam, M.K. A Comparative Analysis of Early-Stage Diabetes Prediction using Machine Learning and Deep Learning Approach. In Proceedings of the 2021 6th International Conference on Signal Processing, Computing and Control (ISPCC), Solan, India, 7–9 October 2021. [CrossRef]
35. Beghriche, T.; Djerioui, M.; Brik, Y.; Attallah, B.; Belhaouari, S.B. An Efficient Prediction System for Diabetes Disease Based on Deep Neural Network. *Complexity* **2021**, *2021*, 6053824. [CrossRef]
36. Mahesh, T.R.; Kumar, V.D.; Kumar, V.V.; Asghar, J.; Geman, O.; Arulkumaran, G.; Arun, N. AdaBoost Ensemble Methods Using K-Fold Cross Validation for Survivability with the Early Detection of Heart Disease. *Comput. Intell. Neurosci.* **2022**, *2022*, 9005278. [CrossRef]

37. Geman, O.; Chiuchisan, I.; Ungurean, I.; Hagan, M.; Arif, M. Ubiquitous healthcare system based on the sensors network and android internet of things gateway. In Proceedings of the 2018 IEEE SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Cloud & Big Data Computing, Internet of People and Smart City Innovation (SmartWorld/SCALCOM/UIC/ATC/CBDCom/IOP/SCI), Guangzhou, China, 8–12 October 2018; pp. 1390–13958.
38. Arif, M.; Philip, F.; Ajesh, F.; Izdrui, D.; Craciun, M.D.; Geman, O. Automated Detection of Nonmelanoma Skin Cancer Based on Deep Convolutional Neural Network. *J. Healthc. Eng.* **2022**, *2022*, 6952304. [CrossRef]
39. Munishamaiaha, K.; Rajagopal, G.; Venkatesan, D.K.; Arif, M.; Vicoveanu, D.; Chiuchisan, I.; Izdrui, D.; Geman, O. Robust Spatial–Spectral Squeeze–Excitation AdaBound Dense Network (SE-AB-Densenet) for Hyperspectral Image Classification. *Sensors* **2022**, *22*, 3229. [CrossRef]
40. Dai, Y.; Wang, G.; Dai, J.; Geman, O. A multimodal deep architecture for traditional Chinese medicine diagnosis. *Concurr. Comput. Pract. Exp.* **2020**, *32*, e5781. [CrossRef]
41. Ramamurthy, K.; Menaka, R.; Kulkarni, S.; Deshpande, R. Virtual doctor: An artificial medical diagnostic system based on hard and soft inputs. *Int. J. Biomed. Eng. Technol.* **2014**, *16*, 329. [CrossRef]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Abstract
The stochastic interpolation (SI) framework of function recovery from input data comprises a de-convolution step followed by a convolution step with row stochastic matrices generated by a mollifier, such as a probability density function. The choice of a mollifier and of how it gets weighted, offers unprecedented flexibility to vary both the interpolation character and the extent of influence of neighbouring data values. In this respect, a soft computing method such as a genetic algorithm or heuristic method may assist applications that model complex or unknown relationships between data by tuning the parameters, functional and component choices inherent in SI. Alternatively or additionally, the input data itself can be reverse engineered to recover a function that satisfies properties, as illustrated in this paper with a genetic programming scheme that enables SI to recover the analytical solution to a two-point boundary value convection–diffusion differential equation. If further developed, this nascent solution method could serve as an alternative to the weighted residual methods, as these are known to have
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