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## DEVELOPMENT OF IoT BASED SMART INVERTER FOR ENERGY METERING AND CONTROL

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**Abstract.** Insufficient power generation has facilitated the search for alternative power generation, as the world is gradually making the transition to renewable green energy sources as a replacement for fossil fuels and other conventional power generation methods that causes environmental pollution. One of these methods is the use of solar energy for electricity generation through the use of the photovoltaic solar inverter which harnesses the power from the sun to generate electricity. The inability of electricity distributors to provide enough and sustainable power supply for homes and businesses, coupled with the need to live a smart life has made humans sort for an easier control method of electricity generation and usage. Hence, this research presents a smart voice and mobile application control modular inverter integrated with a smart metered energy distribution system, which equally distributes power amongst the users for effective and smart energy usage. A test of applied load on the inverter as compared to normal electricity usage deduced an 8% error rate giving a 92% accuracy for the inverter. The mobile app was tested for both online and offline usage and a 67% accuracy was deduced as the overall accuracy of the software. This gives an inference that the system can be fully operated by a user in the luxury of their comfort. For smart meter monitoring and energy allocation, 93.33% and 96.8% accuracy and precision were achieved respectively. This research makes the usage of green energy more efficient with its feature which allows for equal distribution of energy. The system also helps prevent energy theft or misuse by providing only the proper user with alerts and administrative control.

**Keywords:** *Smart Energy Meter, Voice Automation, Smart Switching, IoT.*

**Rezumat.** Generarea insuficientă a energiei a facilitat căutarea unei generații alternative, deoarece lumea realizează treptat tranziția la surse regenerabile de energie verde ca înlocuitor pentru combustibilii fosili și alte metode convenționale de generare a energiei care provoacă poluarea mediului. Una dintre aceste metode este utilizarea energiei solare pentru generarea de energie electrică prin utilizarea invertorului solar fotovoltaic care valorifică puterea soarelui. Incapacitatea distribuitorilor de energie electrică de a furniza o sursă de energie suficientă și durabilă pentru case și afaceri, împreună cu nevoia de a trăi o viață



inteligentă, i-au făcut pe oameni să caute o metodă de control mai ușoară a producerii și utilizării energiei electrice. Această cercetare examinează un inverter modular pentru controlul aplicațiilor mobile și voce inteligentă integrată cu un sistem inteligent de distribuție a energiei, care distribuie în mod egal puterea între utilizatori pentru o utilizare eficientă și inteligentă a energiei. Un test al sarcinii aplicate pe inverter în comparație cu utilizarea normală a energiei electrice a dedus o rată de eroare de 8%, oferind o precizie de 92% pentru inverter. Aplicația mobilă a fost testată atât pentru utilizare online, cât și offline și a fost dedusă o precizie de 67% ca acuratețe generală a software-ului. Acest lucru conduce la concluzia că sistemul poate fi operat pe deplin de către un utilizator în luxul confortului său. Pentru monitorizarea contoarelor inteligente și alocarea energiei, au fost atinse 93,33% și, respectiv, 96,8% acuratețe și precizie. Această cercetare face ca utilizarea energiei verzi să fie mai eficientă datorită caracteristicii sale care permite o distribuție egală a energiei. Sistemul ajută, de asemenea, la prevenirea furtului sau a utilizării greșite a energiei, oferind alerte și control administrativ doar utilizatorului corespunzător.

**Cuvinte cheie:** *Contor inteligent de energie, Automatizare voce, Comutare inteligentă, IoT.*

### **Introduction**

On account of the modern revolution, electricity is the major component that fuels a nation's economy. Businesses, homes and the public authorities are vigorously subjected to constant electricity for all-day activities. Electricity is a form of energy that can be produced either by heat (sun), water (hydro), wind (windmill) or from wasted materials to power devices that creates heat or light. Methods of electricity generation have distinctive advantages over each other and there has never been the best method to generate electricity. Researchers are constantly searching for an alternative, better and safer means of electricity generation [1]. The methods of electricity generation mostly used include hydro and fossil fuels which have resulted in a continuous increase rate of flooding and environmental contamination from gasoline generators exhaust causing environmental hazards [2]. Besides from contaminating the air and polluting the environment, these methods have been identified as the main factor contributing to the increase in greenhouse gas effect in the atmosphere. Also, less reliance and the disappointing nature of electricity generation boards especially in developing countries has resulted in a huge loss of revenue for businesses and organizations [3]. Therefore, it is imperative to zero in on the idea of utilizing sustainable energy effectively thereby generating and storing electricity from secondary sources to reduce the tension and congestion on power grids.

One of the methods of generating zero-emission, and better reliable electricity is through Solar inverters. With rising innovative advances, solar inverters have become one of the most reliable options for the generation of electricity, storage and distribution of electricity which is more even brilliant than the normal power grid. This involves the trapping of the sun using Photo Voltaic (PV) cells and storing the electric charge produced in a battery [4]. Direct current electricity generated by photovoltaic systems is converted to alternating current using converters, which are harmonic sources. [5]. Solar photovoltaic (PV) energy has become a substantial and important renewable energy source in the global energy market, and it is growing. This expansion is owing to continuous improvements in efficiency, power, and reliability, among other factors [6]. The optimum use of this technology could cover a huge piece of the energy interest in many developing countries. Utilizing its different viewpoints is extremely needed especially in a country like Nigeria where there is no constant

electricity and the slow/gradual upgrade to existing grids have not been sufficient to cater for the increasing needs of electricity users.

Inverters assume a vital role in any solar-based energy generation framework and it is frequently defined as devices that converts Direct Current (DC) to Alternating Current (AC) at required frequency and voltage using energy dissipated from the sun. Integration of renewable energy sources has sparked widespread attention in recent years as a means of reducing fossil fuel emissions, alleviating load demand congestion, and lowering electricity prices in the power generation market. This is due to the ease with which inverters, which are commonly utilized in residential applications, can be installed and used. Solar inverters should have a digital design, robust software facilities, and two-way communication capability to make the system intelligent; a system of robust, reliable, and proficient silicon-based hardware that can be controlled by an adaptable software environment control structure capable of remote controlling for faster and better control. This control interface can be developed by employing IoT technology to achieve high reliability with reduced human stress through adequate control using wireless technologies like Bluetooth, Wi-Fi or RFID. Hence, this research presents a smart voice and mobile application control modular inverter integrated with a smart metered energy distribution system, which equally distributes power amongst the users. This system provides accurate measurement of power consumption and displays it to the consumer via a mobile android application for remote monitoring. Also, the system helps to eliminate power wastage due to negligence, inadequate control, and multiple access to the inverter by unauthorized persons.

### **Review of Related Work**

A Smart Energy Meter (SEM) is an electronic device that includes an energy meter chip, data connection protocols, security features, and a data display interface for tracking electric energy usage [7]. Smart meters are distinguished from traditional energy meter systems by their ability to communicate. A smart meter may track active power consumption as well as other information such as voltage and current phasors, reactive power, maximum power demand, frequency, and power factor in real-time. With the progress of technology and the use of IoT, smart meters must be developed to utilize device and communication technologies to achieve user satisfaction [4]. Such devices can be enhanced with capabilities such as multi-level indicators [7, 8], advanced and artificial intelligence-based control policies [9, 10], user-friendly interface [11, 12], energy management system [13], IoT capabilities [1] and other additional functions [14]. This section presents the recent advances in inverter development. Renewable energy sources are now being employed to address energy demands as a result of increased energy demand and pollution caused by rapidly depleted fossil fuels [15]. Solar energy, which uses PV (Photo Voltaic) modules to generate power, is one of the most widely used renewable energy sources. By charging batteries during the day and then utilizing the stored energy in the battery when the sun isn't shining, solar energy can be used to generate and store power. Smart inverters are inverters that convert Direct Current (DC) to Alternating Current (AC) [16], are possibly charged by solar energy, and can track the sun as designed in [8]. Smart inverters, on the other hand, are inverters that communicate in both directions with the user and other stakeholders in the system [17] also, show that such a system exists [4] presented a smart inverter that communicates with the user in a two-way manner, telling the user of the inverter as well as the run time of the loads that the user chooses to operate. Loads are also regulated electronically to enhance human comfort. The study focuses on

improving power supply dependability for high-demand loads, particularly critical loads. [2] shown how to make a smart home with a Raspberry Pi and a smart inverter. This study presented a bi-level (Supervisory-Local) PV-based microgrid system for low-power residential applications. At the supervisory level, a long-term control scheme is assigned to determine the setpoints for local controllers. [18] also includes a variety of instruments, electronic technology, and software. The present PV system monitoring methods have some limitations, such as limited automation and slow response times. These problems can be prevented with a good remote environment information monitoring and control system. This system should include automatic diagnosis procedures in the PV station. In addition, a study published in [19] proposed an "IoT-based smart energy meter" for efficient energy usage. It's crucial for the electrical system's development of a smart grid. As a result, the smart grid's power usage monitoring and control is a primary focus. One of the challenges with the energy meter is the lack of full-duplex transmission. A smart energy meter based on the Internet of Things is presented as a solution to this problem. The smart energy meter manages and computes energy use using an ESP 8266 12E Wi-Fi module and sends the data to the cloud, where the consumer or customer can examine the results.

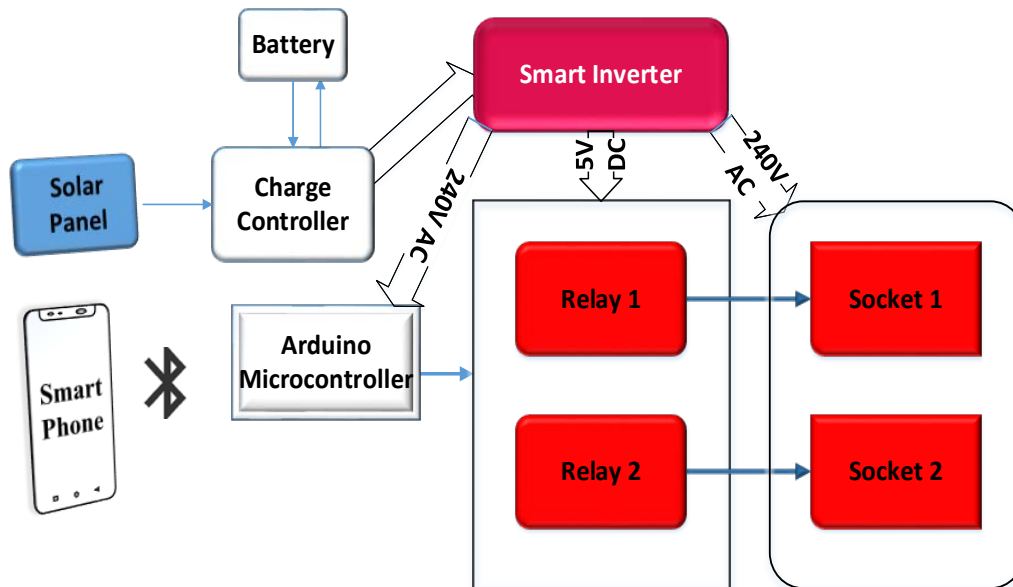
A smart inverter integrated with Raspberry Pi for smart home was proposed by [20]. The inverter can be controlled using a mobile phone so far there is an internet connection on the user's phone. The system is adapted with an Infrared (IR) sensor which monitors the state of the appliances connected to the system. Once the status of any of the systems is triggered from ON to OFF or otherwise, the state new state is stored in a database and displayed on a pre-developed website. Users can also turn on and off the appliances at their convenience over the Web-Application. A similar system is developed by [21]. The basic difference between these systems is that the latter uses LCD to monitor current, voltage and power consumption and can be controlled using a GSM module. The implementation of the smart meter can be integrated into a power grid as discussed by [22]. This requires stepping up or stepping down the power supplied to the power grid by the inverter such that if the grid voltage is 230V and the inverter supply 300V, the inverter voltage is stepped down to 230 V and vice versa. This is done through a PWM inverter. This type of inverters can be controlled using an intelligent micro inverter control scheme that continuously contains Volt-Var control, Low Voltage Ride Through (LVRT) and system frequency response [23].

In terms of speech, mobile application control, and smart energy monitoring and allocation, the proposed method in this study differs from the reviewed relevant studies. When compared to the research in [20 - 22], the system's method of control is a web application and voice control via Bluetooth capable of controlling the modular inverter remotely through wireless fidelity communication technology (Wi-Fi), which makes the use of green energy more efficient with its feature that allows for equal energy distribution. The technology also helps to avoid energy theft or misuse by restricting notifications and administrative control to only the appropriate users.

### **Design Methodology**

This section presents the design, development and working principles of the developed smart modular solar Inverter system. The system comprises two parts: software and hardware. The voice control unit and mobile application control mechanism (a touch control interface for smartphones) are used to control the modular inverter, while the hardware is made up of numerous units that make up the modular inverter system. The

technique is divided into three sections: solar inverter development, metering, and energy allocation; voice module control unit creation, and mobile application for the modular inverter. The aim of this research is to develop a smart energy metering and switching modular inverter which is controlled by the voice of a user and also through the mobile application software. The system is a solar inverter where energy from the sun is harvested using a Photovoltaic Solar panel and boosted using a buck-boost converter. The harnessed energy is then stored in a battery through the charge controller as shown in Figure 1.



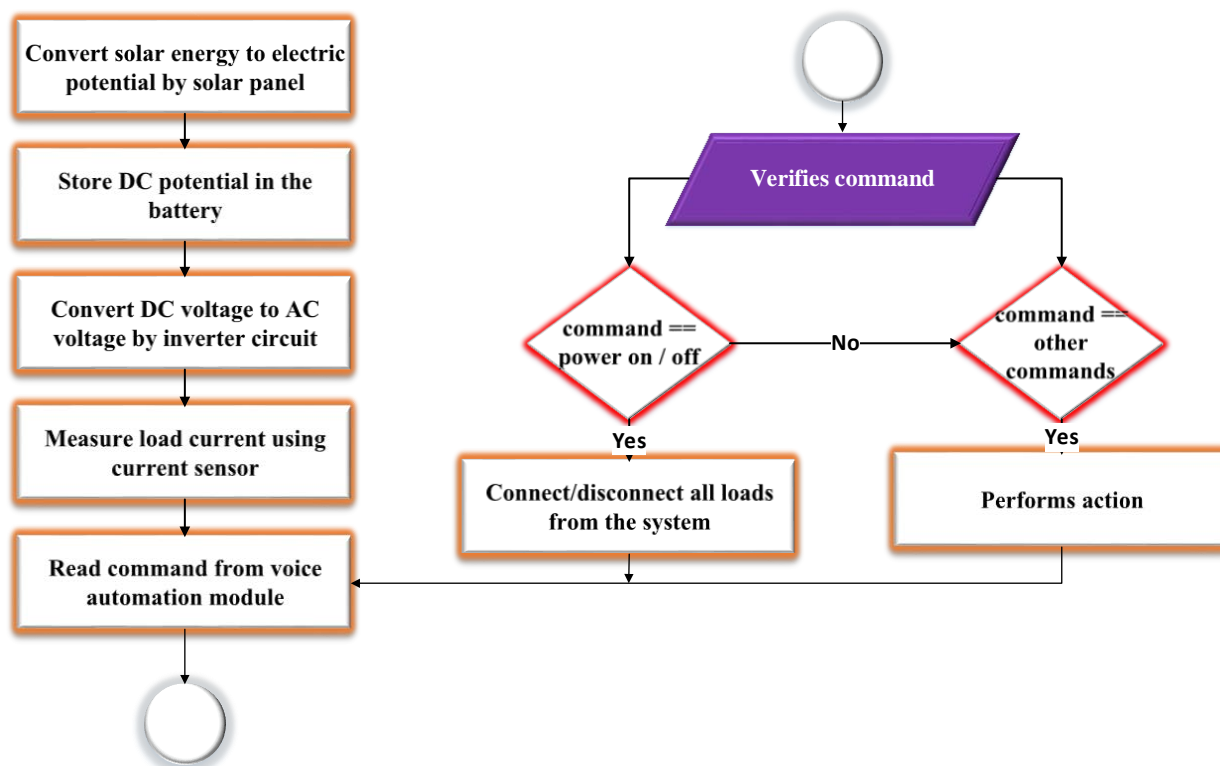
**Figure 1.** System Block Diagram.

The energy stored in the battery is in form of direct current (DC) and there is a need for conversion into alternating current (AC) because home appliances use alternating current (220V to 240V). This is done through the inverter. The meter controller monitors the power dissipated on the nodes to ensure that each user uses a considerable amount of power and does not affect the load usage of other nodes (users) connected to the inverter. The switching controller monitors the connected load on each of the inverter nodes, alert the user if there is an erratic current dissipated in any node and switch off that node to ensure that there is no excess current from any of the connected loads. The voice-based controller for the system allows the user to control the inverter through an IoT medium (mobile app). The mobile application serves as a means of single-user authorization access and security for inverter usage. The system's controlling functions include power on/off the whole circuit, or the individual circuits connected to the system respectively. The mobile application is also the medium by which the user previews the monitoring function of the inverter. Figure 2 shows the data flow chart of the system.

### Development of the Switching and Metering Module

The switching and Metering module consist majorly of a current sensor which is set to measure DC and AC for 20A. The three-output pin of the current sensor is connected to the microcontroller while the wire in and wire out pin are connected to the inverter battery to measure the current being drawn by an external device.

The module is connected in series with the relay to avoid short circuits and to accurately monitor the current going to each channel on the relay.

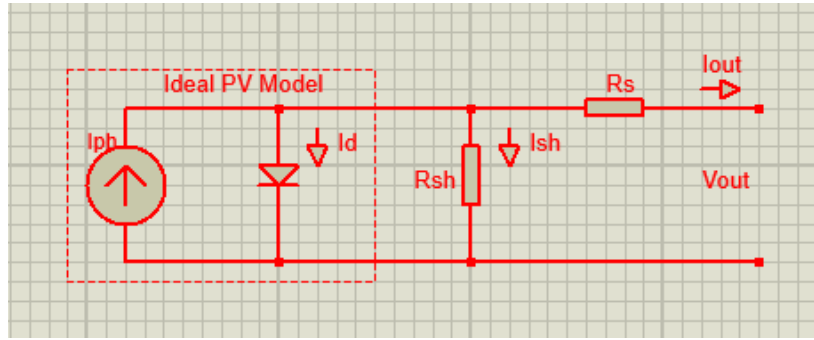


**Figure 2.** System Flow Chart.

The metering function is also enabled through ESP8285 ESP-M2 NodeMcu microcontroller through the current sensor which measure, distribute and regulate each power connected to the nodes of the inverter. When a node exceeds the total amount of power dedicated to it, it triggers the node off. Also, the current sensor senses loads used by each socket on the inverter. When the 20A threshold is reached, the sensor automatically cut off the supply to that node and alerts the user through the mobile application. As shown in Figure 1, the system comprises a Solar panel; Charge controller; Inverter; Voltage sensor; Current sensor; ESP8285 ESP-M2 NodeMcu Wi-Fi development board; Liquid crystal display (LCD); Relay switch and Loads.

### PV Solar Panel

The 12V monocrystalline solar panel is placed at an angle of  $45^\circ$  to the sun. This angle is chosen so that the reflection of the sun can directly hit the PN junction on the solar panel. Presumably, the output load is in form of DC, it can be connected to load directly to the panel but there is a need for conversion to AC if the application involved is an AC load. The solar cell is represented in Figure 3 by a single diode circuit. 12 volts / 150 watts is effective in the study. When exposed to the open Sun, a solar panel may produce a peak of 12 volts at 12500 mA. The overall load applied to the solar panel will determine its rating. Four 15-watt energy-saving bulbs, a 100-watt projector, six 200-watt laptop computers, a 60-watt standing fan, a 100-watt television, a 50-watt Go-TV decoder, and twelve 7-watt phones are among the selected loads. In watts, total load =  $(15 \times 4) + 100 + (200 \times 6) + 60 + 100 + 50 + (7 \times 12) = 1654W = 1.654KW$ . We have chosen to add some ability to deal with extra random little force utilization gadgets making the determined absolute burden of 1.7KW. Force in KVA = power in watt/power factor = power in KW/0.8. Force in KVA =  $1.7/0.8 = 2.125KVA$ . The solar panel power rating required is 2.125KVA (Kilovolt-Amperes).



**Figure 3.** Equivalent circuit of the Solar Cell.

The output current of the circuit is calculated as shown in equations 1 to 4.

$$I_{out} = I_{ph} - I_{sat} \left( e^{(q \cdot V_{out} + R_s \cdot I_{out})} - 1 \right) - \left( \frac{V_{out} + R_s \cdot I_{out}}{R_p} \right) \quad (1)$$

$$I_{ph} = \left[ I_{sc} + K_1 \cdot (T - T_r) \right] \frac{G}{G_n} \quad (2)$$

$$I_{sat} = I_{rs} \cdot \left( \frac{T}{T_r} \right)^3 \cdot \exp \left\{ \frac{q \cdot E_{gap}}{K \cdot A} \left( \frac{1}{T_r} - \frac{1}{T} \right) \right\} \quad (3)$$

$$I_{rs} = \frac{I_{sc}}{\exp \left( \frac{q \cdot V_{oc}}{N_s \cdot A \cdot k \cdot t} \right) - 1} \quad (4)$$

In equations 1 to 4,  $I_{sat}$  is the reverse saturation current,  $I_{ph}$  is the photocurrent source,  $A$  is the ideality factor,  $k$  represents Boltzmann constant ( $1,3806503 \cdot 10^{-23}$  j/°k),  $T$  is the solar cell surface temperature,  $R_s$  is the series resistance,  $R_p$  is parallel resistance,  $I_{sat}$  is short circuit current,  $k_i$  is a measure of open-circuit voltage,  $T_r$  is reference temperature of the solar cell,  $I_{rs}$  is reverse saturation current at a reference temperature,  $E_{gap}$  is the energy bandgap  $q$  is electron charge ( $160217646 \cdot 10^{-23}$ °C),  $V_{out}$  is open-circuit voltage and  $N_s$  is the number of cells connected in series. Equation 5 describes the Maximum Power ( $P_{max}$ ) and the Parallel Resistance ( $R_p$ ) of the solar cell is expressed in equation 6.

$$P_{max} = V_{mp} \cdot I_{out} \quad (5)$$

Given that,

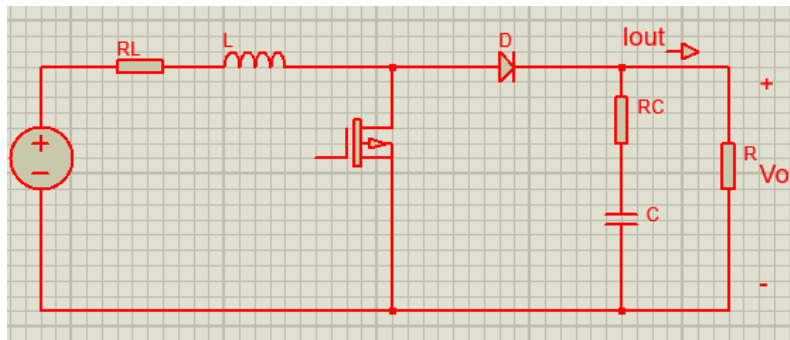
$$I_{out} = I_{ph} - I_{sat} \left( e^{(q \cdot (V_{out} + R_s \cdot I_{out}))} - 1 \right) - \left( \frac{V_{out} + R_s \cdot I_{out}}{R_p} \right) \quad (6)$$

$$P_{max} = V_{mp} \cdot \left\{ I_{ph} - I_{sat} \left( e^{(q \cdot (V_{mp} + R_s \cdot I_{mp}))} - 1 \right) - \left( \frac{V_{mp} + R_s \cdot I_{mp}}{R_p} \right) \right\} \quad (7)$$

$$R_p = \frac{V_{mp} + R_s \cdot I_{mp}}{\left\{ V_{mp} \cdot I_{ph} - V_{mp} \cdot I_{sat} \cdot \left( \exp \left( \frac{q \cdot (V_{mp} + R_s \cdot I_{mp})}{N_s \cdot A \cdot k \cdot t} \right) - 1 \right) - P_{max} \right\}} \quad (8)$$

**Boost Converter**

By short-circuiting and open-circuiting the MOSFET as shown in figure 4, the boost converter was utilized to convert a variable and low Direct Current (DC) source to a constant and higher DC voltage periodically. If the solar inverter's input side is a PV system, this assists to get the highest efficiency.  $V_c$  represents the input voltage,  $L$  is the impedance,  $R_L$  is the resistance input inductance,  $D$  is the diode,  $R_c$  is the output capacitor's resistance, and  $C$  is the output capacitor's and  $V_m$  is the MOSFET voltage. The power dissipated is represented as  $P_o$ .



**Figure 4.** Schematic of A Bulk Booster.

The output voltage of the bulk booster is calculated as shown in Equations 9 to 10.

$$V_o = \frac{(R + R_c) \cdot (1 - D) \cdot R}{\Delta} \cdot V_G - \frac{(R + R_c) \cdot (1 - D) \cdot D \cdot R}{\Delta} \cdot V_M - \frac{(R + R_c) \cdot (1 - D)^2 \cdot R}{\Delta} \cdot V_c \quad (9)$$

$$\Delta = (R_L + R_M) \cdot (R + R_c) + (R \cdot R_c + R \cdot R_D + R_c \cdot R_D - R \cdot R_M - R_M \cdot R_c) \cdot (1 - D) + R^2 \cdot (1 - D)^2 \quad (10)$$

The output power when the switch is opened is calculated as shown in equation 11.

$$P_o = \frac{V_o^2}{R} = \frac{V_s^2}{(1 - D)^2 R} \quad (11)$$

**Charge Controller and Solar Battery**

In solar power systems, the charge controller is a crucial component. It is the charge administrator, especially when a battery bank is involved in the system. This manages and controls the battery's charge. It keeps the battery from being overcharged and also prevents the battery from being discharged. A lead-acid battery with a capacity rating of 12v/100AH was employed in this study. The lead-acid battery belongs to the rechargeable and secondary battery categories. Despite the battery's low energy-to-volume and energy-to-weight ratios, it can deliver higher surge currents. These are the batteries that turn chemical energy into electrical energy by using lead peroxide and sponge lead. Because of the enhanced cell voltage levels and low cost, these are commonly used in substations and power systems. Equation 12 is used to calculate the charging time of a battery in ideal conditions.

$$T_b = \frac{A_p}{I} \quad (12)$$

Where  $T_b$  is the battery charging time and  $A_p$  is the battery ampere-hour rating while  $I$  represent the current in ampere when  $10\% A_p + 1\% A_p$  for power loss.

### Solar Inverter

The electricity generated by the solar panels is direct current. Alternating currents power the majority of our appliances. As a result, the direct current from the solar panel must be converted to an alternating current to power the appliances, which is where the inverter comes in. The size of the inverter should be 25-30% larger than the total Watts of the appliances. As a result, we estimate the inverter to be 30% larger than the total wattage of the appliances.  $1.3 \times 1.7 \text{ KW} = 2.21 \text{ KW}$  (about). In KVA, the power rating is  $1.7 / 0.8 = 2.125\text{KVA}$ .

### Development of the Voice Control Module

The Voice module is made up of an Android app that is integrated using Google Speech-To-Text Application Programming Interface (API). The mobile application is designed to first prompt Bluetooth connection when there is no prior Bluetooth connection on the users' phone when the application is newly launched. This is because the system uses Bluetooth for connectivity and also as a security measure because Bluetooth has a maximum connectivity distance of ten (10) meters and a single user connection at a time. Once the pairing is achieved, the user can proceed to input the command through voice automation. The speech is immediately converted into matching text format and transmitted to the microcontroller through the HC05 Bluetooth Module. Figure 5 present the use-case diagram of the voice control module, while Figure 6 presents the flow chart of the voice control.

The generated text is used to control/trigger the output sockets/load that would be connected to the inverter output. If the command received through the Bluetooth matches a correct pattern as programmed on the microcontroller, the appropriate circuit is powered on or off.

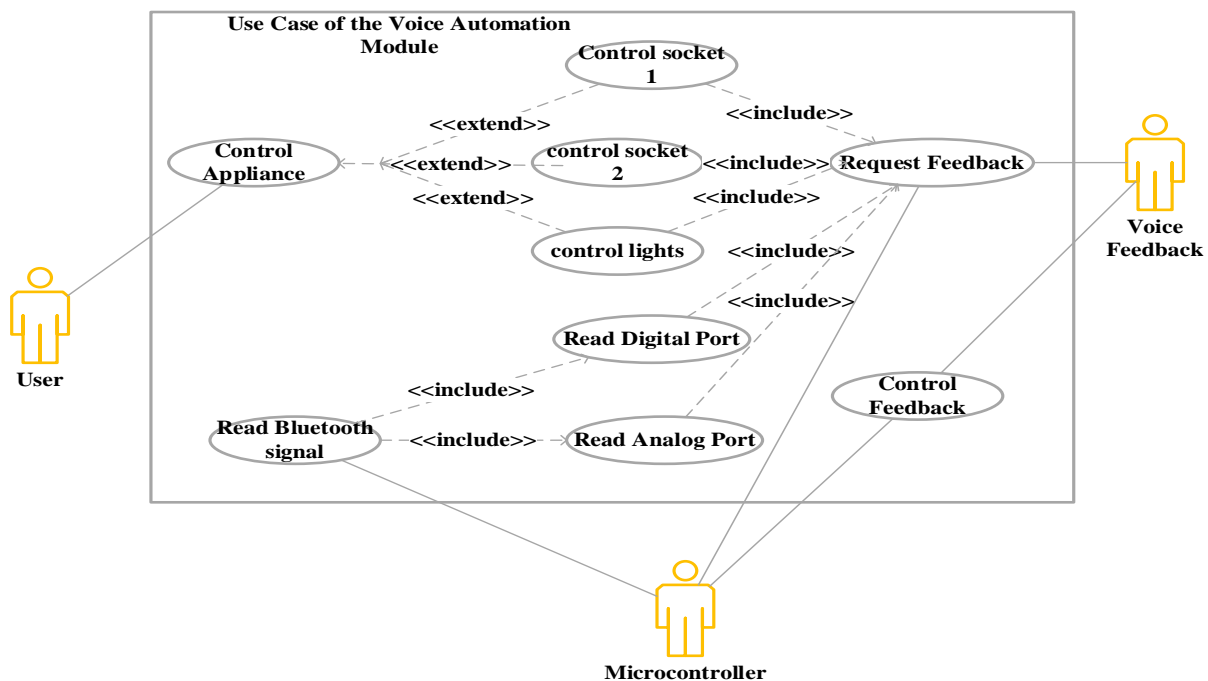


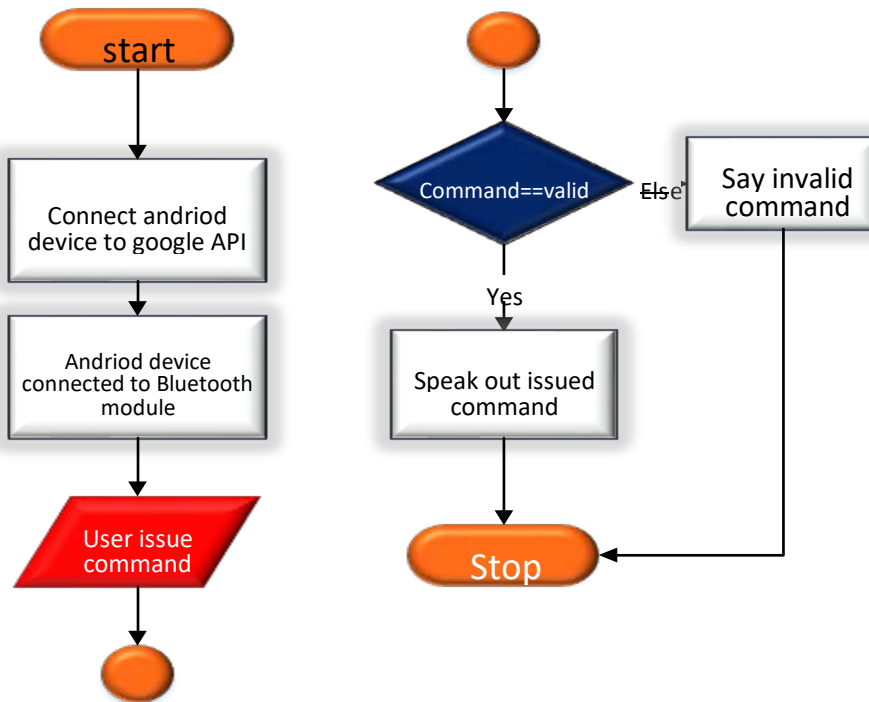
Figure 5. Use Case Diagram for the Voice Control Module.



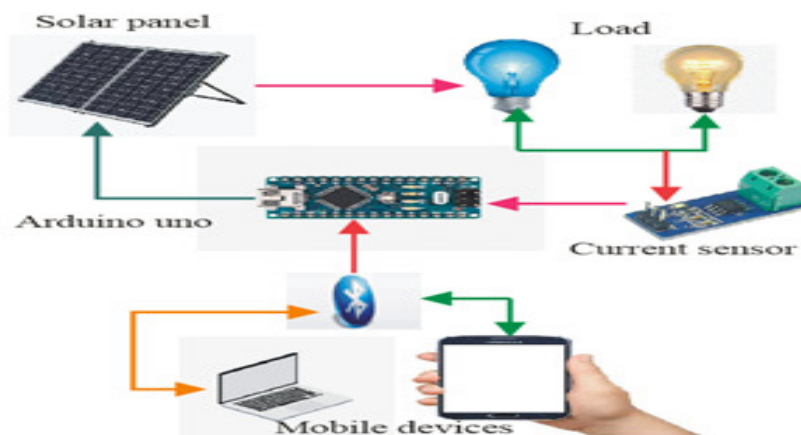
The mobile app is also used to monitor the load from the outlets of the inverter. It is developed with prompting and switching functionality that alerts the user when there is erratic load(s) on a socket terminal and advises the user to switch the load to another socket terminal of the inverter.

**Development of the Mobile Application Control Module**

This section presents smart inverter control using the mobile application. The system smart socket of the system is controlled using an IoT medium (mobile application). This mobile app serves as a means of single-user authorization access and security for inverter usage. The system’s controlling functions include power on/off the whole circuit, or the individual circuits connected to the system respectively. The block diagram of this developed module is shown in Figure 7.



**Figure 6.** Flow Chart of the Voice Control.



**Figure 7.** System Application Control Model.

### Performance Evaluation

The accuracy, response time, and precision of the proposed system were used to assess its performance. The time it takes for the voice input to produce an output, as well as the time it takes for the mobile app to respond to a command from the Google API. The precision rate is based on how closely the system repeats the values.

#### Accuracy

The accuracy of a system's calculated and measured values refers to how near they are to the actual value of the quantity being measured. Equation 13 is used to calculate the system's accuracy.

$$E = \frac{TLV - SMV}{TLV} \times 100\% \quad (13)$$

Where E denotes the percentage error, TLV denotes the tested load value, and SMV is the system measured value. Equation 14 was utilized as a metric to evaluate the similarity between the inputted signal and the actions carried out on the inverter as outputted by the user to determine the correctness of the mobile application module.

Accuracy, 
$$\sigma = \frac{N_c}{T_i} \quad (14)$$

#### Precision

Precision is how close the readings are when repeated several times. It will be carried out in the system to see how precise the system reacts to the mounted voltage and power consumption in the inverter. This is shown in equation 15.

$$\text{Precision} = \frac{\text{Measured Value} - \text{Actual Value}}{\text{Actual Value}} \times 100 \quad (15)$$

#### Response Time

The system response time is done to observe the time it takes for the connection to be established between the system Bluetooth module and the mobile application. It takes note of the time it takes to respond to the external load and its maximum input. As the time it takes to send command from the controller to the peripheral devices in charge of disconnecting overall voltage and current above the threshold of the minimum voltage programmed in the microchip. To calculate the response time, it takes the system to accept input and produce the required output as prompted by the user as shown in equation 16.

$$\text{Response time} = \frac{T_i}{T_o} \quad (16)$$

Where  $T_i$  is the amount of time it takes to process the input and  $T_o$  is the amount of time it takes to trigger the correct output. The processing time of the Arduino and the mobile application is also factored into the response time.

### Results and Discussion

The result of the created modular inverter with optimum energy allocation and smart control system is presented in this part. This comprises hardware assembly, software application development, and system performance evaluation. The results of the system's testing are tabulated, and graphs are presented for analysis. Accuracy, response time, and

precision are the criteria employed. Accuracy was used to assess the system's ability to provide multiple correct outputs based on the number of collected inputs. The time it took the software to handle valid and incorrect commands was measured using Response Time. Precision was utilized to assess the system by looking at how close the readings were when they were repeated numerous times.

### Software Development for Smart Energy Distribution

The mobile android application software (Smart Energy Distributor) was developed with MIT Application inventor development and it employs the use of firebase database for the storage and management of data such as username, password and data acquired from the inverter module. Figure 8(a) present the login page of the mobile application, while Figure 8(b) presents the smart energy distributor page which monitors and control the system.

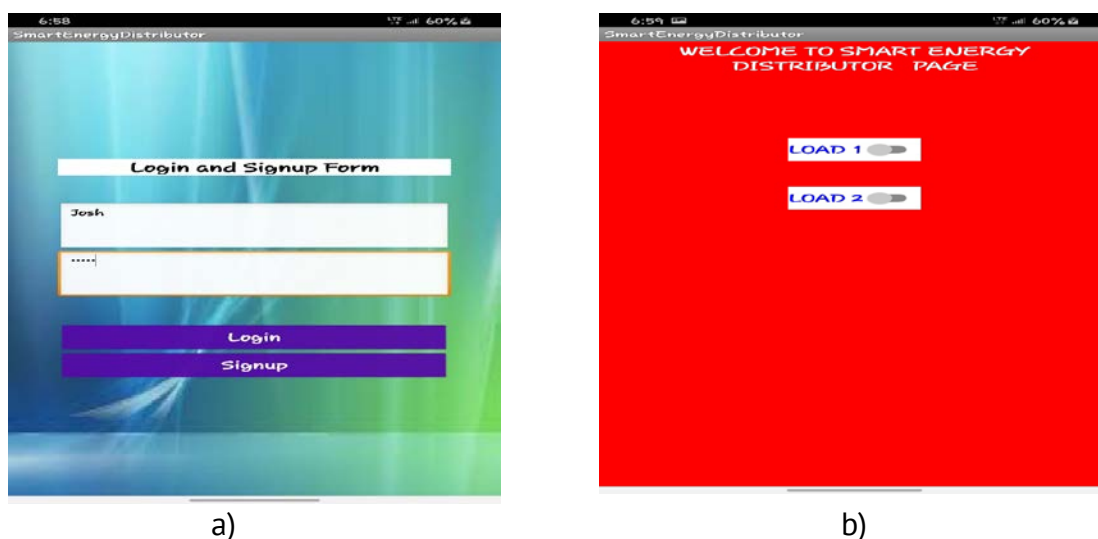


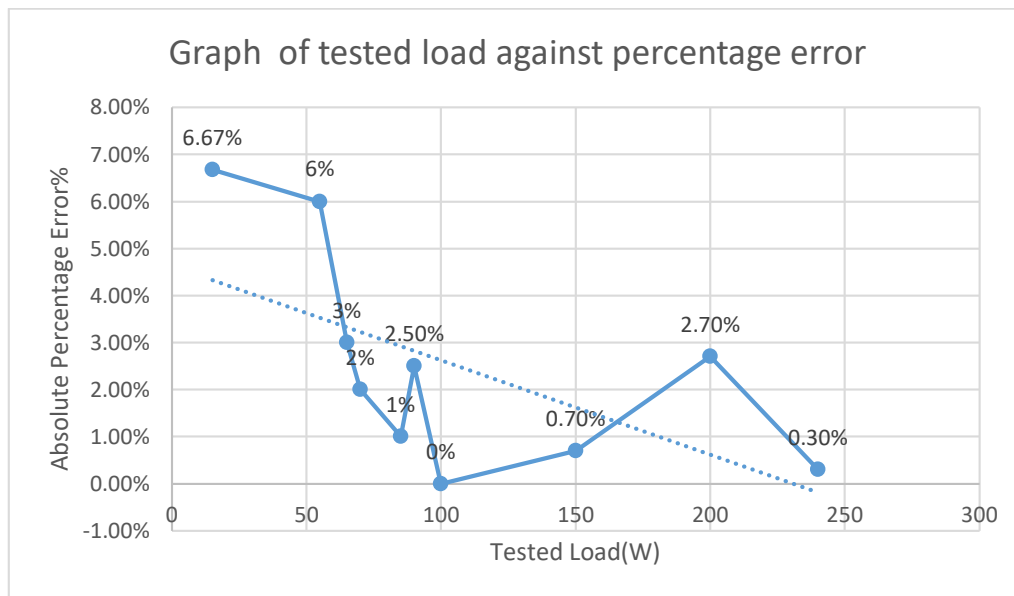
Figure 8. Application Page: (a) Login Screen, and (b) Smart Energy Distributor Mobile Application.

Table 1 present the tested load (w), system measured power (w), and absolute percentage error, while figure 9 shows the accuracy of the system on the load. From figure 9, it can be deduced that the measured values are close enough to the actual value of the tested load with a maximum calculated percentage error of 6.67 per cent. Hence the system performed optimally with 93.33% accuracy.

Table 1

Table of Accuracy Test

S/N	Tested Load (W)	System Measured Power (W)	Percentage Error (%)
1	15	14	6.6
2	55	51.5	6
3	65	62.9	3
4	70	68.6	2
5	85	84.1	1
6	90	87.7	2.5
7	100	100	0
8	150	148.9	0.7
9	200	205.4	2.7
10	240	239.1	0.3



**Figure 9.** Graph Showing the Accuracy of the System.

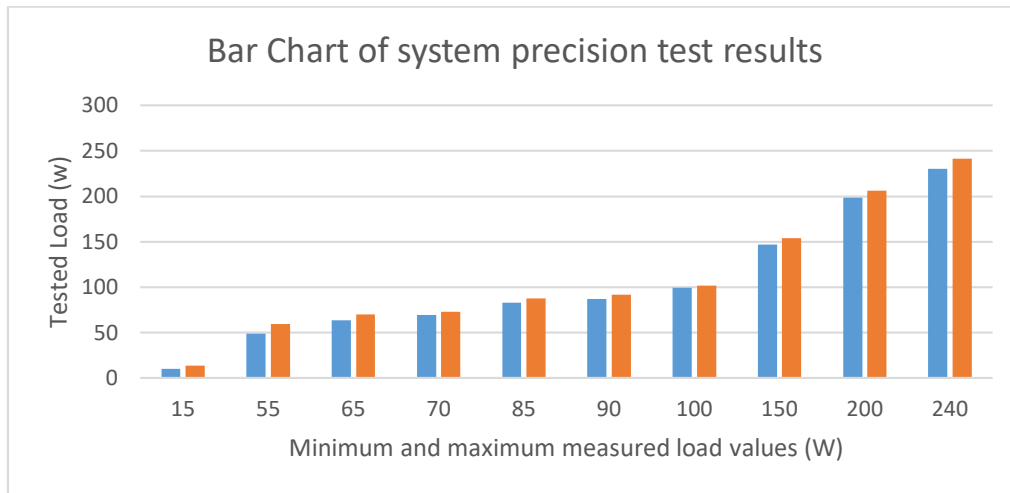
When readings are repeated numerous times, precision refers to how close they are. Table 2 illustrates the findings obtained after repeating the readings up to 10 times for each load tested. As indicated in table 2, the minimum and maximum measurements were tabulated. The graph of the tested load against the minimum and maximum power is shown in Figure 10. The graph shows that the values are consistently measured within a tight range. As a result, the system's readings and measurements are accurate, with a precision of 96.8%.

*Table 2*

Precision Results			
SN	Tested Load(W)	Minimum Power Measured (W)	Maximum Power Measured (w)
1	15	10	13.5
2	55	49.1	59.5
3	65	63.6	70
4	70	69.4	73.3
5	85	83.2	87.9
6	90	87.1	92
7	100	99.5	101.5
8	150	147	154.2
9	200	198.7	206.4
10	240	230	241.3

#### Accuracy Results for Voice Control Unit

The accuracy of the system is determined by plotting the number of correct outputs samples from the voice command against the total number of collected input samples. The developed software was sampled five (5) separate times with five (5) test cases for each sampling time. The numbers were chosen so that all commands can be collected using the software. Table 3 shows the data collected from the software. Figure 11 shows the total accuracy of the developed software. It can be deduced that the mobile application has a total accuracy of 63%.



**Figure 10.** Bar chart showing the precision of the system.

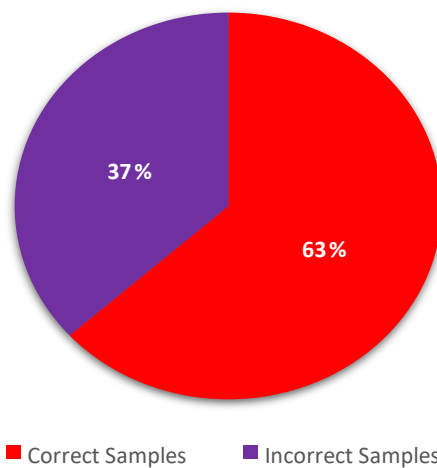
This is due to factors such as “English language fluency of the user”, “intonation of the user”, and “language of the user” as the software is designed to only understand and accept commands in the English language. The software can be said to have considerable accuracy and is usable to perform the actions to which it was developed.

*Table 3*

**Accuracy of the Software system**

Test Cases	Number of Collected input	Number of Correct Outputs
ALL ON	5	4
ALL OFF	5	4
Load One ON	5	2
Load One OFF	5	3
Load Two ON	5	5
Load Two Off	5	3

**Accuracy of Software**



**Figure 11.** Total accuracy of the software.

### Response Time Results

The response time of the system is a measure of the time it takes for the system to perform the actions imputed. This was tested by imputing command via the mobile application and calculating the time the system responds to the command. The software was tested when the mobile application has no data connection (OFFLINE) and data connection (ONLINE) respectively. Result obtained is shown in table 4 and table 5 respectively.

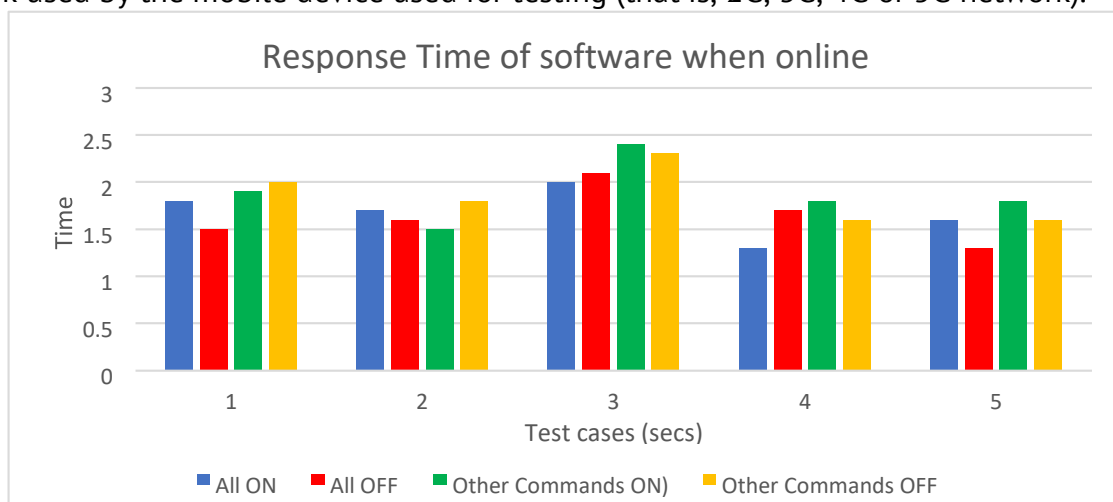
Table 4

Response time of the software system (OFFLINE)				
S/N	All ON (sec)	All OFF (sec)	Other Commands ON (sec)	Other Commands OFF (sec)
1	1.3	1.2	0.9	0.8
2	1.2	1.0	0.8	0.7
3	1.1	0.9	0.7	0.8
4	1.0	0.7	0.5	0.9
5	0.9	0.8	0.6	0.6

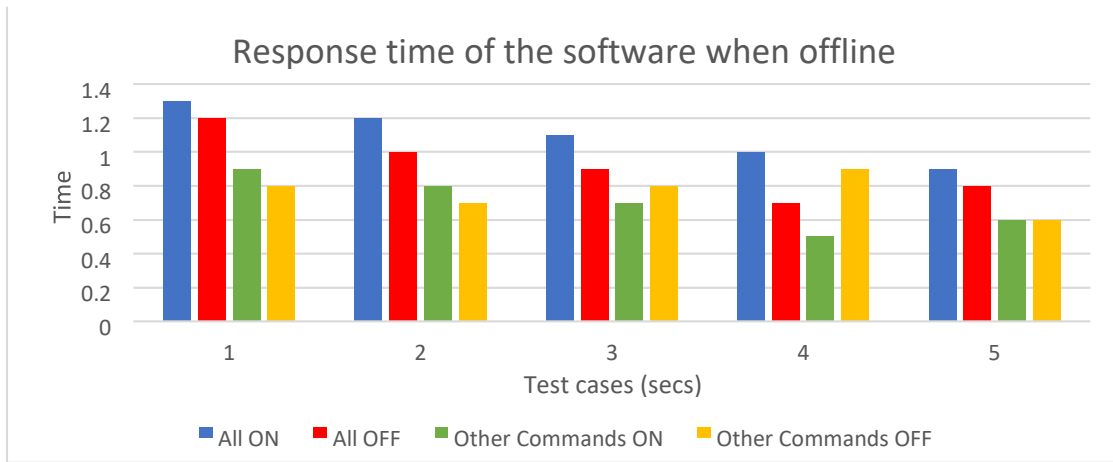
Table 5

Response time of the software system (ONLINE)				
S/N	All ON (sec)	All OFF (sec)	Other Commands ON (sec)	Other Commands OFF (sec)
1	1.8	1.5	1.9	2.0
2	1.7	1.6	1.5	1.8
3	2.0	2.1	2.4	2.3
4	1.3	1.7	1.8	1.6
5	1.6	1.3	1.8	1.6

Figures 12 and 13 represent the response processing time for the software while the mobile device is ONLINE and OFFLINE, respectively. It can be determined from the results that when the device is in online mode, slight imbalances increase the processing time. The reason for this is because the service provider's mobile network fluctuates, as does the type of wireless network used by the mobile device used for testing (that is, 2G, 3G, 4G or 5G network).

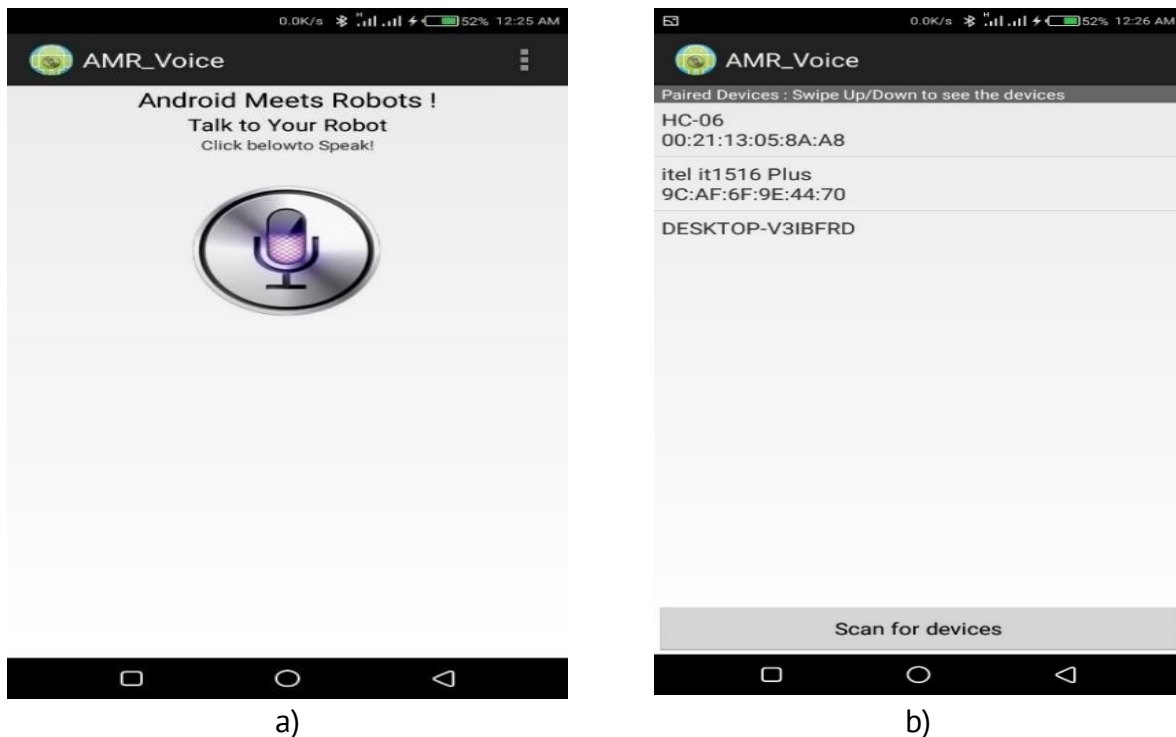


**Figure 12.** Response time when using the software online.



**Figure 13.** Response time when using the software offline.

The interface of the developed software for inverter control through an Android device is shown in Figure 14. When launched, the app automatically triggers the device Bluetooth settings of the device ON. To connect to the Bluetooth module, the button on the right side of the screen is used to navigate to the connection screen (Figure 14b). A user can scroll through the numerous already paired Bluetooth devices to click and connect to the correct Bluetooth device (HC-05). To input commands, the microphone button is pressed. The command understood from the voice command is displayed so that the user can know if the command given is correct or not. Figure 15 depicts the developed system, whereas table 6 depicts the estimated cost in Nigerian Naira for the developed system. The overall cost of the hardware and software is estimated to be N 140, 570.00.



**Figure 14.** Mobile Application (a) Home Interface, and (b) Connection Interface.



Figure 15. Developed System.

Table 6

Bill of Engineering Materials and Evaluation

ITEM	DESCRIPTION	COST (₦)	QUANTITY	AMOUNT(₦)
1	2KVA Transformer less Inverter With Charger	35000	1	35000
2	12V/100AH Inverter Battery GLT Deep Cycle	38500	1	38500
3	20AMP PWM Charge Controller	7000	1	7000
4	2V/150WAH Monocrystalline	24500	1	24500
5	Installation Cable	800	16	12800
6	Arduino Uno	4500	1	4500
7	Capacitors	50	8	400
8	Resistors	10	12	120
9	LCD	1500	1	1500
10	LED	10	5	50
11	Bluetooth Module	3000	1	3000
12	2-Channel Relay	2500	1	2500
13	Loudspeaker	1000	1	1000
14	PAM 8403 Amplifier Module	1000	1	1000
15	Sockets	500	2	1000
16	Casing	1500	1	1500
17	9V Battery	200	1	200
18	I/O Connectors	500	2	1000
19	Wires	500	10	5000
<b>Estimated Cost of Project</b>				<b>140,570.00</b>



## Conclusion

This research successfully presented a modular inverter with optimized energy allocation and smart control systems. It was implemented by integrating a mobile application with functionalities such as powering, remote monitoring, switching and control of the inverter, thereby achieving constant optimization of the power flow of the inverter battery. This was achieved by integrating a mobile application and voice control with a smart socket module which was integrated into a solar inverter system. From the results, the system was able to control the power consumption by varying the amount of the load connected to the system. When the load exceeds the threshold, the system will be notified of excess power consumption which will be preceded by immediate advice to cut off supply. This accounted for over 50% of power being conserved, thereby saving the battery life from excess load above its threshold. In addition to the fact that solar-powered inverters help reduce environmental pollution, this research further makes the usage of green energy more efficient with its feature which allows for proportionate or equal distribution of energy. It allows for easy remote monitoring through the mobile application and the introduction of the concept of IoT. The system also helps prevent energy theft or misuse by providing only the proper user with alerts and administrative control.

## Future Directions

Numerous changes can be made to the current design and technology, as well as numerous new features that can be added:

- Increasing the capacity of the system or adding support for general power distribution of the general power supply to help make it more efficient and less costly for its users.
- The subsequent systems can look into the addition of a GSM module to the system which will allow remote monitoring and control of the device through a short messaging service (SMS) using the AT command (Attention command).
- GPS tracking can also be integrated into the system, allowing the position of the solar inverter module to be determined in the case of theft.
- The mobile application should be embedded with security measures (login) like biometrics login, and key login to ensure that the system is not used by intruders.

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## REPUBLIC OF MOLDOVA POWER ENERGY IN THE PANDEMIC

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**Abstract.** The anti-COVID restrictions have resulted in a reduction of the total world energy consumption. At the same time, the transfer of the activities to home increased the household consumption of electricity by up to 30%. In the Republic of Moldova, the total electricity consumption in 2020 decreased compared to 2019 by 0.22 %, while household consumption increased by 3.5%. In the first quarter of 2021, household consumption increased by 7.8%, raising the share of household consumption to 45.5 %. Working from home has proven to be convenient for both employees and employers, so the trend is expected to remain after the pandemic crisis. In this context, a series of energy efficiency and renewable energy solutions in residential buildings are expected to be implemented.

**Keywords:** COVID-19, household electricity consumption, energy efficiency, renewable energy.

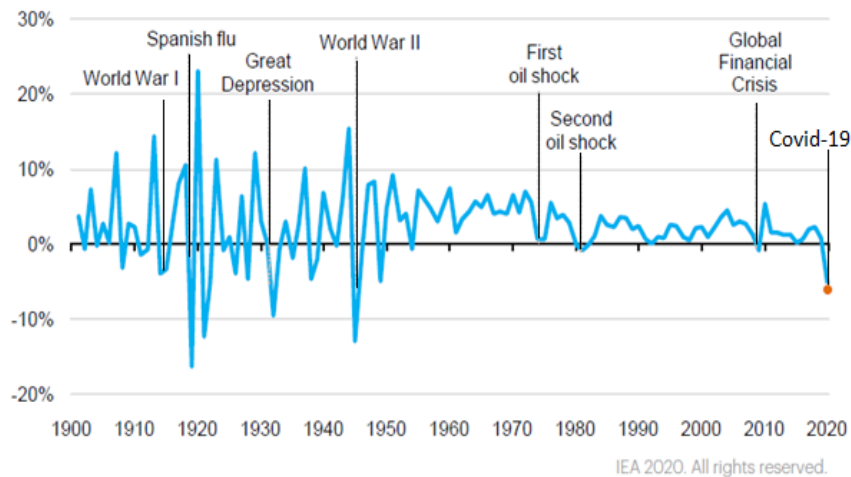
**Rezumat.** Restricțiile anti-COVID au condus la o reducere a consumului total de energie la nivel mondial. În același timp, transferul activităților la domiciliu a crescut consumul casnic de energie electrică cu până la 30%. În Republica Moldova, consumul total de energie electrică în 2020 a scăzut față de 2019 cu 0,22%, în timp ce consumul casnic a crescut cu 3,5%. În primul trimestru al anului 2021, consumul casnic a crescut cu 7,8%, ponderea acestuia ridicându-se la 45,5%. Munca de acasă s-a dovedit a fi convenabilă atât pentru angajați, cât și pentru angajatori, așa că este de așteptat ca tendința să rămână după criza pandemiei. În acest context, apare necesitatea implementării la clădirile rezidențiale a unei serii de soluții de eficiență energetică și energie regenerabilă.

**Cuvinte cheie:** COVID-19, consum casnic de energie electrică, eficiență energetică, energie regenerabilă.

### Introduction

Energy, being intercalated with all aspects of human activity, it does react to all the cataclysms and calamities that society is going through. In "Figure 1" is shown the recent rate of primary energy consumption changes, beginning with 1900.

Thus, the major events that took place from the early twentieth century to the present days, including two world wars, several major economic crises, two flu pandemics (Spanish flu 1918-1920 and recently COVID-19) were followed by significant reductions in the growth rate of energy consumption, with the deepest decline seen after pandemics.



**Figure 1.** Rate of change in global primary energy demand, period 1900-2020 [1].

The SARS-CoV-2 virus originated in China in December 2019, by February 2020 spread to 41 countries, currently affecting 220 countries and territories, with the number of infected cases exceeding 220 million, and deceased reaching over 4.5 million [1, 2].

### **The impact of the pandemic on the global energy sector**

In order to slow virus, spread, governments around the world have imposed restrictions on most social and economic activities. These included partial or complete lockdowns of schools and non-essential businesses and prohibition of public gatherings, social distance, travel bans, work-from-home policy. The limited restrictions reduce the weekly energy consumption by up to 15%, the partial lockdown - by 10÷27%, the total lockdown by 15÷33%. Since first quarter of 2020 coal demand fell compared to the first quarter of 2019 by 8%, oil demand by almost 5%, gas demand by about 2%, and the global energy demand fell by 3.8%. Electricity demand during total lockdowns has decreased in several countries by 20% and above. In total, by 2020 the demand for electricity has decreased in China by 3%, in the USA by 5%, in the European Union by 5% [1]. Worldwide electricity consumption has decreased by 4% [3]. Although lockdown measures have significantly reduced the demand for electricity due to the impact on the industrial sector and commercial buildings, however electricity consumption in the residential sector has increased during the full lockdown period by 11÷32% [4]. It is not only as a result of residents being confined to their apartments, as such, however also due to the transfer to work from home. At the same time, it can be noticed that the average daily peak power does not increase and the profile of the diurnal load curve in the morning hours is plateauing to the level of the maximum power that occurred in the similar period of time before the lockdown. The peak power of the sections feeding the different numbers of households also remained virtually unchanged [5, 6].

It is noticeable that, along with the total reduction in electricity demand, its production from renewable sources, which is less affected by restrictions and largely unaffected by demand, has increased worldwide in 2020, compared to 2019, by 6.3% [7]. The decrease in production from fossil fuels and increasing renewable energy have reduced CO<sub>2</sub> emissions by 5.8% or almost 2 Gt which constitutes the largest drop ever and almost five times the decline of 2009 following the global financial crisis [8]. If the increase in hydroelectric energy production is favorable for electric power systems, the variable wind and photovoltaic energies cause some difficulties for the system operators.

### Pandemic and energy of the Republic of Moldova

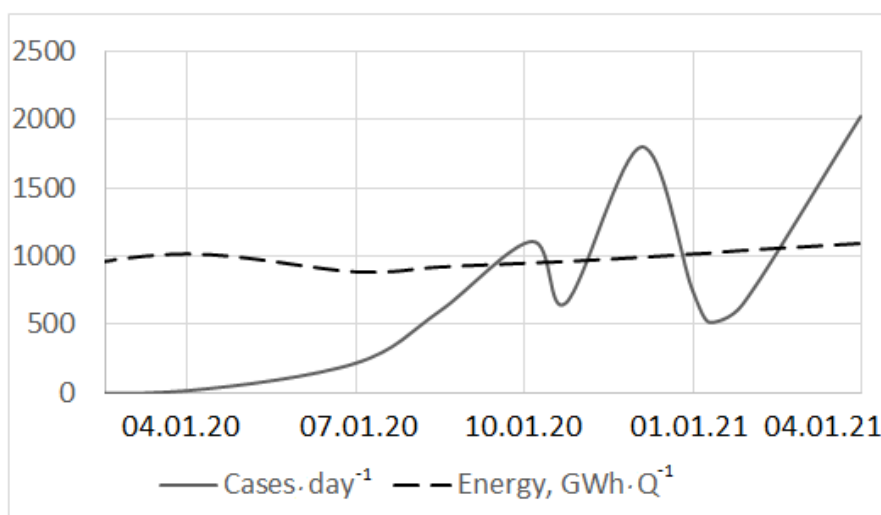
In the Republic of Moldova (Moldova) the first case of COVID-19 was confirmed on March 10, 2020. Restriction measures were initiated the same day. According to Decision no. 6 from March 10, 2020 of The National Public Health Emergency Commission of the Republic of Moldova a number of restrictions have been introduced such as: banning mass meetings, suspending the educational process within educational institutions, prohibiting access inside the subordinated institutions of the persons returned from COVID-19 infected regions, etc.

By Decision no. 9 from March 15, 2020, restrictions were introduced on the activity of commercial and public catering units. On May 15, 2020, a state of public health emergency was issued on the entire territory of the Republic of Moldova for the period May 16 - June 30, 2020, which was then extended periodically. During the summer months the National Public Health Emergency Commission lifted some restrictions, however in the fall, on November 27 the "Code Red" alert level was initiated in all administrative-territorial units of the republic. In January of 2021, again, some restrictions were lifted, unfortunately to be followed by re-imposed State of emergency and the "Code Red" in February-March, which were enforced until April [8].

The vast majority of the country's national economy sectors have felt the negative impact of the pandemic. In the second quarter of 2020, the Gross Domestic Product decreased in real terms of 14%. The most affected areas are those involving population interactions and movement, and also those in the informal economy. Thus, the decrease in the HoReCa sector was 66.2%, theater, recreation; pleasure declined by 45.8%, the decrease in the passenger transportation sector was above 50%. At the same time, there was noticed an increase in computers and telecommunications equipment sales, which in the first half of the year registered an increase of 56% due to the transition to online schooling, and also the teleregime of work of some employees. There has also been a substantial increase in the information technology sector [9].

During the year 2020 among the republic population were registered approx. 145 thousand diseased and approx. 3 thousand deaths.

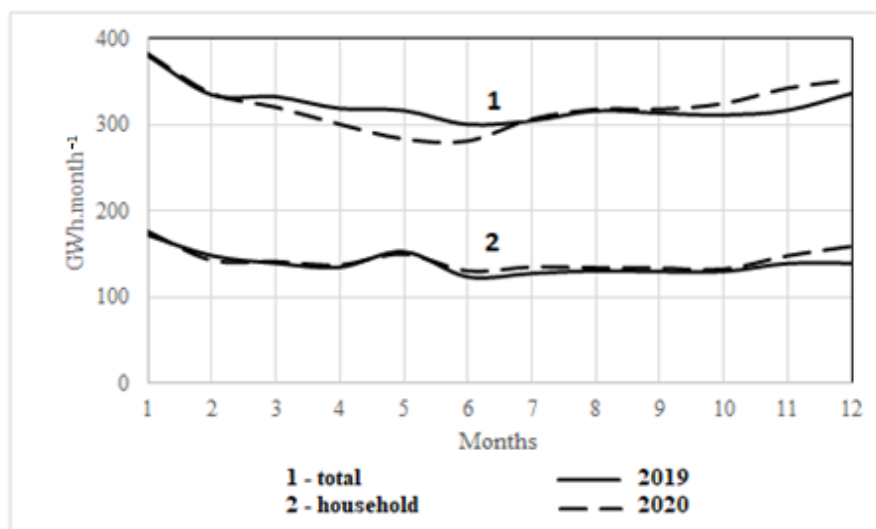
The epidemic evolution [8, 9] and the consumption of electricity [10] between March 2020 and April 2021 are presented in "Figure 2".



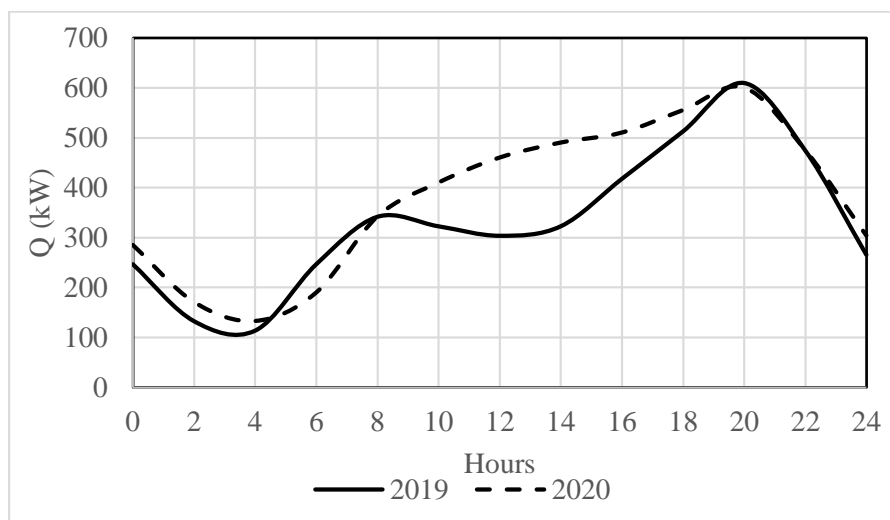
**Figure 2.** The development of the COVID-19 pandemic and the consumption of electricity in the Republic of Moldova.

During that period of time, the pandemic went through three waves, each of them with increasing amplitudes: 1149 cases of newly diseased per day in October 2020, 1715 cases per day in December 2020 and 2132 cases per day in March 2021. With the introduction of restrictions, electricity consumption decreased in the second quarter of 2020, but subsequently, with the limiting of some restrictions and the declining attention to some of them, by ordinary citizens and, also, by the supervisory bodies, consumption increased slowly, both total and household consumption (see “Figure 3”). In the second half of 2020, both consumptions exceeded those of the previous year.

“Figure 4” shows the daily load curve of an electrical substation serving a neighborhood of 9 residential blocks. The curves are reflecting a day in mid-September with similar characteristics: average temperature +16 °C, mid-week. There is a marked increase in load during buisnes hours 8.00 to 19.00, the peak of the load remaining virtually the same: 610 kW until the pandemic and 600 kW during the lockdown.



**Figure 3.** The dynamic of energy consumption in the Republic of Moldova in 2020 compared to 2019.



**Figure 4.** The daily load curve of a residential neighborhood in the lockdown and the same period of time prior the pandemic.

The quarterly energy consumption in the evaluated time frame is presented in “Table 1” [10]. Total electricity use decreased insignificantly in 2020 compared to 2019, by only 0.22%,

Table 1

<b>Progression of electricity use in the Republic of Moldova during the 2019, 2020, 2021</b>						
<b>Quarter</b>		<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>Annual</b>
Total (GWh)	2019	1072.64	936.69	920.09	945.69	3875.10
	2020	1015.50	886.53	950.34	1014.2	3866.56
Variation 2020/2019 (%)		-5.33	-5.36	3.29	7.24	-0.22
Household (GWh)	2019	458.7	410.36	386.89	407.33	1663.28
	2020	459.4	418.43	404.18	439.26	1721.27
Variation 2020/2019 (%)		0.15	1.97	4.47	7.84	3.49
Household share (%)	2019	42.76	43.81	42.05	43.07	42.92
	2020	45.24	47.20	42.53	43.31	44.52
Total 2021 (GWh)		1089.9	970.9			
Variation 2021/2020 (%)		7.33	9.52			
Household 2021 (GWh)		495.4	437.7			
Variation 2021/2020 (%)		7.8	4.7			
Household share 2021 (%)		45.5	45.1			

while household consumption increased by 3.5%. The high rate of household power consumption stands out, it was 42.9% in 2019 and 44.5% in 2020 while in the European Union the rate is 31% [11], and in the USA - 22% [12]. In the first quarter of 2021, household use has increased by 7.8% compared to the respective period of time in 2020, the total power use by 7.3%, with the household consumption rate reaching 45.5%.

Table 2

#### Sources of electricity acquisition in the Republic

<b>Sources</b>	<b>2019 (GWh)</b>	<b>2020 (GWh)</b>	<b>2020/2019 (%)</b>
Import	3509.1	3418.4	-2.58
Fossil fuels	659.6	723.4	9.67
Hydro	58.3	46.7	-19.90
Wind	36.915	50.138	35.8
PV	1.437	3.275	127.9
Biogas	28.748	27.793	-3.3
Total	4301.9	4269.8	-0.75

The insignificant reduction in consumption, compared to other countries', is mainly explained by two factors: first the high rate of household consumption and second the fact that most factories in the Republic of Moldova are part of food industry and cannot be kept in lockdown.

The structure of electricity purchasing in the republic is presented in “Table 2”. The difference between the amount of energy purchased and delivered is accounted for the losses in the networks and is less than 10%. The share of renewable sources in electricity production, which constitutes more than 15% of the domestic product, has increased by 8.5%. This grow

was due to photovoltaic panels (127.9%) and wind installations (35.8%). The drought in 2020 reduced the production of hydraulic energy by 19.9% and of the biomass-based energy by 3.3%. The production of other primary energy sources has undergone changes within the limits of variation in previous years. Electricity imports decreased by 1.3% [13 - 15].

### **Post-pandemics solutions**

Working from home has proven to be convenient for both employees and employers. Employers have reduced their expenses with the maintenance and workspaces servicing, on the other hand employees are relieved from wasting time and money and from the inconveniences of traveling to work and back. In addition to that, for many employees, working from home is more convenient than in often crowded office buildings. That is why this change is expected to continue after the pandemic crisis is resolved. In this setting, the main focus is on residential buildings where a series of energy efficiency and renewable energy solutions are suggested, in order to improve living conditions and reduce energy consumption and CO<sub>2</sub> emissions, such as:

- Increasing the efficiency of home appliances, computers and office equipment used in working from home;
- Increasing the efficiency of the ventilation and air conditioning systems equipment of the work spaces in order to reduce the energy consumption and to improve the quality of the indoor air;
- Maximum use of natural lighting;
- Thermal rehabilitation of buildings to reduce both heat input in summer and heat loss in winter, especially in buildings heated by electricity or heat pumps;
- Using of smart thermostats to adjust temperature settings according to changing in buildings occupancy patterns, especially when a large number of residents are staying at home;
- Implementing umbrellas and blinds use to optimize the heat exchange of the buildings with the environment, as well as the access to daylight, depending on the season and the particular heating and cooling needs;
- Implementing of integrated photovoltaic systems for buildings on the roofs, walls, windows, shading devices; these systems can meet the entire electricity demands of the residential buildings;
- Installation of combined photovoltaic and thermal (PV / T) collector systems for the simultaneous production of electricity and residential hot water.

Increasing use of electricity storage installations, both systemic and individual (neighborhoods, individual house), as the increase in the rate of variable renewable energy (solar and eolian) will increasingly complicate the work of system operators. Storage will increase the resilience of the energy supply to ensure its availability at the scene during network outages.

These solutions will be needed both for existing buildings, repairs, reconstructions and rehabilitations, and especially for the design of new buildings, with a tendency towards "green houses". To implement them, it is necessary to involve decision-makers to include them in energy programs that are targeting residential buildings. In the Republic of Moldova, energy efficiency programs and renewable sources are applied to social objects: schools, kindergartens, orphanages. It is necessary to expand these programs to include residential buildings. Energy literacy of this population of this area is also needed. For the Republic of



Moldova, which imports over 80% of electricity and in which domestic electricity consumption is close to half of total consumption, these actions will give a significant result.

### Conclusions

The restrictions on social and economic activities during the pandemic reduced total electricity consumption. However, it increased household consumption, both by keeping tenants at home and by switching to work and education from home. Work from home has proved convenient for both employees and employers, which is why it is expected to persist even after the resolution of the pandemic crisis. As a result, there rises the need to apply a series of energy efficiency and renewable energy solutions to residential buildings. Increasing the rate of variable renewable energy involves the development of electricity storage installations. In the Republic of Moldova, it is rational to expand the existing energy efficiency and renewable sources programs, on social objects, and on residential buildings.

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## OPTIMIZATION OF THE THERMAL TRANSFER PROCESSES FOR ELEMENTS APPLIED ON GARMENT PRODUCTS

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**Abstract.** The main objective of the paper is optimization of the process of thermal transfer in order to obtain - with minimum number of tests and maximum precision - a high adhesion degree of stencils applied to the garments. The major factors affecting the thermal transfer processes are: temperature, pressure, time, and the characteristics of the textile (fiber composition, finishing, structure of the face surface, etc.). The problem is current for most companies that produce clothing for sports and outdoor activities. This category of products is quite complex due to processing technology, combinations of various textile components, cutout components and most importantly the informative and decorative elements applied through thermal transfer process. To optimize the thermal transfer process, a series of experiments with a central rotating compound were applied. Analysis and Interpretation of the results showed that the pressing time is the most important factor of the adhesion of the thermal transfer to the textile material and its ulterior resistance to washing.

**Keywords:** *central rotating compound plan, design of experiment, optimization, sportswear, thermal transfer.*

**Rezumat.** Obiectivul principal al lucrării constă în optimizarea procesului de transfer termic pentru a obține - cu un număr minim de teste și precizie maximă - un grad ridicat de aderență a șabloanelor aplicate pe articole de îmbrăcăminte. Factorii majori care afectează procesele de transfer termic sunt: temperatura, presiunea, timpul și caracteristicile materialului textil (compoziția fibrelor, finisarea, structura suprafeței feței etc.). Problema este actuală pentru majoritatea companiilor care produc îmbrăcăminte pentru sport și activități în aer liber. Această categorie de produse este complexă datorită tehnologiei de prelucrare, combinațiilor de diverse componente textile, componente decupate și cel mai important, a elementelor informative și decorative aplicate prin procesul de transfer termic. Pentru a optimiza procesul de transfer termic, s-au aplicat o serie de experimente cu un compus rotativ central. Analiza și interpretarea rezultatelor au arătat că timpul de presare este cel mai important factor al aderenței transferului termic la materialul textil și al rezistenței sale ulterioare la spălare.

**Cuvinte cheie:** *plan compus rotativ central, proiectarea experimentului, optimizare, îmbrăcăminte sport, transfer termic.*

## Introduction

Nowadays clothing for sports and outdoor activities is a fairly important segment of global clothing production. In terms of complexity, performance, design and comfort that it has to provide, it exceeds the requirements for the ordinary clothing [1]. Sportswear and clothing for outdoor activities must ensure the necessary comfort while practicing sports and they have to be resistant to a variety of external factors. This could be achieved through the right choice of materials and design. The textile materials used for sportswear have undergone a significant evolution of performance in terms of elasticity and local pressures on the human body, antibacterial properties and ensuring thermal comfort [2 - 5].

In the same way the attached elements carrying a manufacturer's logo, trademark or other information applied, in most cases, through thermal transfer, they must be resistant to repeated stress by stretching, bending, abrasion and repeated washing.

Heat transfer printing means application at a high temperature (120-190°C) of a design (drawings, images, inscriptions, etc.) on various target surfaces using special intermediate materials (thermal transfer film/foil or special paper for thermal transfer) [6,7]. The image is applied to special paper or film and is transferred to the target surface using a thermal press.

The use of heat transfer has a number of advantages over other printing technologies:

- ✓ the transfer of very fine lines and small details, which allows the image to be more precise and natural;
- ✓ unlike sublimation and direct printing, thermal transfer printing allows the decoration of fully finished products (with zippers, buttons, applied pockets, with prominent parts of the products); color images with photographic quality can be applied, which is impossible to achieve with screen printing, and the color brightness is much higher than when using sublimation printing;
- ✓ heat transfer allows you to print images in large quantities and apply them to products as needed, regardless of the material - this allows you to change the product model, color and materials;
- ✓ the main advantage of heat transfer over other printing technologies is the speed of order execution.

Effects such as glitter, hologram, or reflective can be easily obtained by thermal transfer [8].

The review [9] presents developments in transfer printing and the various factors that affect transfer printed product quality besides dyes, and how these factors affect the transfer printing process. In order to obtain a qualitative result, the optimal values of the three technological parameters must be established and later maintained. Those parameters are pressure, temperature and time of exposure to temperature under pressure [10, 11].

With the implementation of new high-performance fibers in sportswear textiles, methods and techniques for finishing them were developed and proposed, including heat transfer printing and application of various emblems, logos etc. [12, 13].

Following the analysis of the experience of CSM Uniform regarding the technologies applied for the manufacturing of clothing (Montura brand) and experience in manufacturing clothes for active sports, it was found that the problem of obtaining the quality that meets the requirements of the beneficiaries and current standards requires constant changing of thermal transfer parameters, thus involving of specialists. Starting from this aspect, the

purpose of this paper was to study and determine how the quality of the print by heat transfer printing depends on the fibrous composition of the textile material and to establish the optimal parameters to ensure a high quality of the print.

## 1. Research methodology

### 1.1. Materials included in the study

The garments manufactured at CSM Uniform (for Montura brand) are made of the following textiles: knitwear, synthetic fibers, mainly polyamide (PA) and polyester (PES), as well as in various proportions of PA and PES mixture with elastane. Three types of textiles were selected for the research:

- 1) Membrane fabric, article TS442 in green color, made of 100% polyamide fibers, produced with GORE-TEX® ACTIVE technology. Properties: waterproof (up to 28,000 mm of water), made of wind resistant material that allows air circulation (RET <3.5).
- 2) Fabric, article TS286 in black color, made of 86% polyamide and 14% elastane. Properties: density - 137 g / m<sup>2</sup>, elastic, characterized by high wear resistance and water-repellent DWR treatment.
- 3) Knitwear, article JS567, in blue color, made of 59% polyimide and 41% elastane, produced by EUROJERSEY, Sensitive® Fabrics. Properties: provides high protection against UV rays (UPF50) due to SUN-BLOCK treatment of the fabric, anti-pilling.

As an element applied through the thermal transfer process was the Company Logo (EA5) which was cut from black reflective and fluorescent film, made by SISER [14].

### 1.2. Experimental research

The experimental research is aimed at:

- 1) establishing the influence of thermal transfer process's technological parameters like temperature, pressure and time on the output parameter values (adhesion of the thermal transfer film with the brand logo on it to the textile material after 5 washing for 3 types of textile material frequently used in sportswear).
- 2) establishing mathematical models for the thermal transfer process on 3 types of textile materials with different composition;
- 3) optimization of the heat transfer process.

The research was carried out on the basis of a series of experiments according to the central composite rotational design of the second order with three independent variables [15]:

$x_1$  - represents pressing temperature value, °C;

$x_2$  - represents pressure value, atm.;

$x_3$  - represents pressing time value, s.

The zero level, the variation step, the variation limits and the coding of the parameters are presented in "Table 1".

The real values of physical parameters of the thermal transfer process are temperature, pressure and pressing time.

They were selected according to the recommendations of CSM Uniform specialists, and the variation intervals were based on recommendations from the literature.

Table 1

**Experimental range and levels of independent variables  
used in central composite rotational design.**

Independent variables	Range and levels				
	$-\alpha$ (1,68)	-1	0	+1	$+\alpha$ (1,68)
Temperature, °C	150	155	165	175	185
Pressure, atm	2	3	4	5	6
Time, s	3	10	20	30	35

The purpose is to obtain a print with maximum wear-resistance throughout the life span of the clothing products; the measured output parameter is the adhesion after five washings. Its maximum value is the 4th degree according to the scale below.

### 1.3. Method of performing the heat transfer

The heat transfer was performed with the MACPI automatic press, model 346.37 - 9222 series 127600. For each experiment according to the design of experiments, 5 samples of textile material with dimensions of 149 x 210 mm were cut. The foil for thermal transfer with the logo of the Montura brand with dimensions of 30x30 mm was applied to them.

### 1.4. Method of determining the print adhesion

The level of adhesion was determined by testing after 5 consecutive washings of the textile materials samples which were subjected to thermal transfer process. The washings were performed under the following conditions: the first washing was performed after at least 10 hours from the time of application of the thermal transfer, other 4 times were each performed every 24 hours.

The washings were performed in the BOSCH WLX161610E washing machine, temperature was set to 40°C, program was set to synthetic materials, duration of a washing cycle was set to 1 hour and 30 minutes. Detergent used: Ariel 3 in 1 universal, 1 capsule per washing cycle. The experimental samples were dried on a special drying rack at 21-22°C.

Adhesion was determined organoleptically by manual detachment and assignment of points / degrees of resistance according to the scale:

- 1- detaches with minimal effort;
- 2 - satisfactory grip, peels off with greater effort;
- 3 - good adhesion, detaches with a significant effort;
- 4 - excellent adhesion, does not peel off.

## 2. Results and discussions

A design of experiments was made for the realization of experimental variants. Pressing temperature (° C); pressure (atm); time (s) were determined for each variant. The experimental values were processed using the OPTEX software [16].

The computer calculates the coefficient values for the linear and quadratic part of a mathematical model of the formula for a three-variable model  $y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2$ ,

The program checks the significance of the coefficients through Student test and it checks the adequacy of the model through the Fisher - Snedecor test. It was also necessary to further verify the adequacy through the Adler method by calculating the percentage of differences between the measured values and the calculated result, all this information being provided by the program in accessible forms, which can be commented and interpreted by the researcher. Optimization of the print adhesion parameter achieved during the heat

transfer process was performed by analyzing the isocurves resulting from the graphical representation of mathematical models. The graphic representations were made both three-dimensional and as a graph in order to obtain, on the one hand the geometric body that mathematically represents the studied process and on the other hand, the representations in the graph allowed to obtain curves of form  $y = f(x_1, x_3)$  and  $y = f(x_2, x_3)$  used for the technological discussion and the choice of the supposedly optimal or sub-optimal values of the result - the adhesion of the print depending on the temperature, pressure and pressing time. "Table 2" presents the data obtained for the assortment - knitwear from 59% PA + 41% EA.

Table 2

**Central composite rotational design (CCRD) for optimization of three variables in experimental values for heat transfer on knitwear from 59% PA + 41% EA**

Nr.	X <sub>1</sub> cod	X <sub>2</sub> cod	X <sub>3</sub> cod	X <sub>1</sub> real	X <sub>2</sub> real	X <sub>3</sub> real	Ymeasur.	Ycalcul.
1	+1	+1	+1	175	5	30	4	4,157
2	-1	+1	+1	155	5	30	4	4,011
3	+1	-1	+1	175	3	30	4	4,011
4	-1	-1	+1	155	3	30	4	4,364
5	+1	+1	-1	175	5	10	2	2,308
6	-1	+1	-1	155	5	10	1	1,661
7	+1	-1	-1	175	3	10	1	1,661
8	-1	-1	-1	155	3	10	1	1,515
9	-1,682	0	0	150	4	20	4	3,399
10	+1,682	0	0	185	4	20	4	3,645
11	0	-1,682	0	165	2	20	4	3,399
12	0	+1,682	0	165	6	20	4	3,645
13	0	0	-1,682	165	4	3	1	0,045
14	0	0	+1,682	165	4	35	4	3,997
15	0	0	0	165	4	20	4	4,023
16	0	0	0	165	4	20	4	4,023
17	0	0	0	165	4	20	4	4,023
18	0	0	0	165	4	20	4	4,023
19	0	0	0	165	4	20	4	4,023
20	0	0	0	165	4	20	4	4,023

Regression coefficients:

$b_0 = 4.023$	$db_0 = \pm 0.020$	$b_0$ - significant
$b_1 = 0.073$	$db_1 = \pm 0.014$	$b_1$ - significant
$b_2 = 0.073$	$db_2 = \pm 0.014$	$b_2$ - significant
$b_3 = 1.175$	$db_3 = \pm 0.014$	$b_3$ - significant
$b_{12} = 0.125$	$db_{12} = \pm 0.018$	$b_{12}$ - significant
$b_{13} = -0.125$	$db_{13} = \pm 0.018$	$b_{13}$ - significant
$b_{23} = -0.125$	$db_{23} = \pm 0.018$	$b_{23}$ - significant
$b_{11} = -0.177$	$db_{11} = \pm 0.013$	$b_{11}$ - significant
$b_{22} = -0.177$	$db_{22} = \pm 0.013$	$b_{22}$ - significant
$b_{33} = -0.708$	$db_{33} = \pm 0.013$	$b_{33}$ - significant

All regression coefficients of the equation are significant and the response equation is shown below "Eq.(1)".

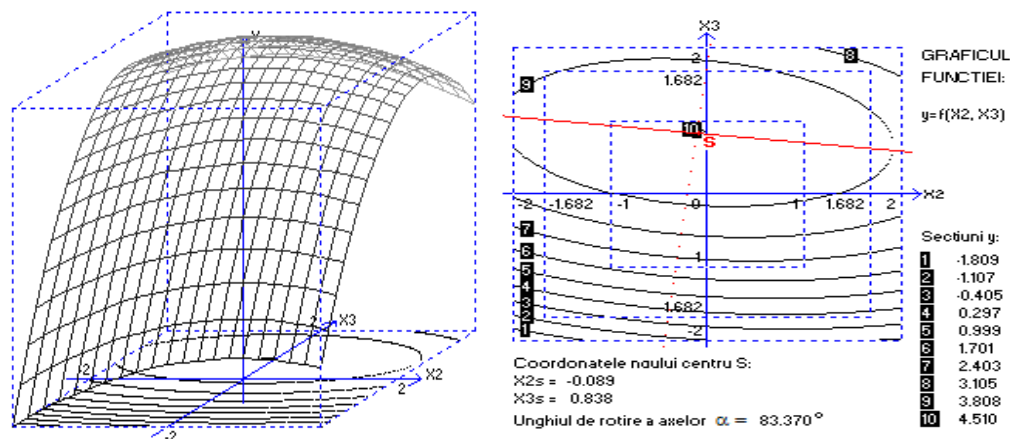
$$y = 4.023 + 0.073x_1 + 0.073x_2 + 1.175x_3 + 0.125x_1x_2 - 0.125x_1x_3 - 0.125x_2x_3 - 0.177x_1^2 - 0.177x_2^2 - 0.708x_3^2 \quad (1)$$

The analysis of the mathematical model suggests that the resultant variable  $y$  of the print adhesion depends on each of the factors  $x_1$ ,  $x_2$ ,  $x_3$  independently, as well as on the interactions  $x_1 \cdot x_2$ ,  $x_1 \cdot x_3$ ,  $x_2 \cdot x_3$ . By checking the coefficient significance with the Student test, it is observed that all the coefficients of the equation are significant. Given the above component of the model, it proves to be adequate, because the calculated value of the Fisher - Snedecor test is lower than the tabulated value of the same test,  $F_{tab} = 5.050$ .

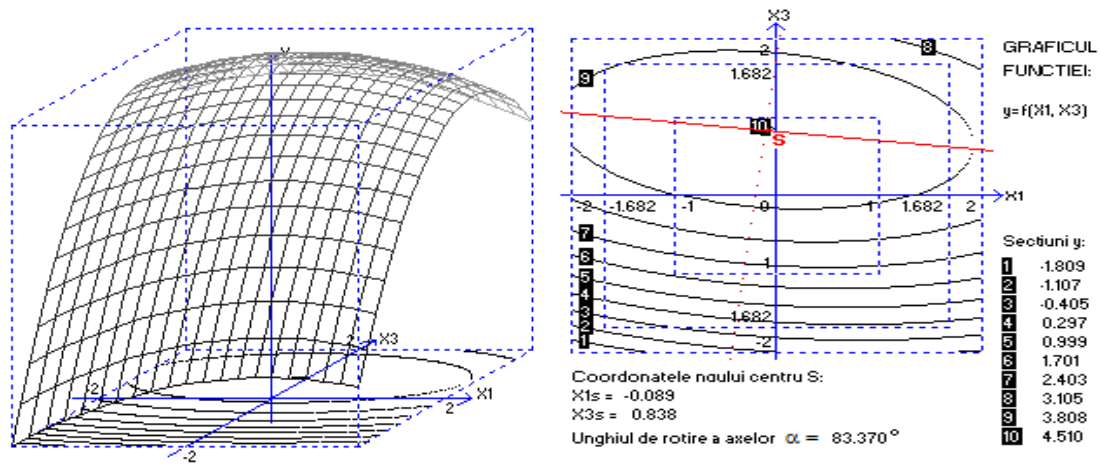
The analysis of the response equation coefficients, which models the variation of the print adhesion obtained by thermal transfer, leads to the following conclusions:

- 1) the linear part of the equation contains all three parameters, which shows that their variation significantly influences the resultant;
- 2) the increase of the values  $x_1$  (temperature),  $x_2$  (pressure) and  $x_3$  (pressing time) leads to the increase of the resultant value with a stronger / considerable influence from the factor  $x_3$  (pressing time);
- 3) it is found that  $x_1$  and  $x_2$  change the result by 1.81%,  $x_3$  changes the result by 29.21%, the influence of the factor  $x_3$  the pressing time is approximately 16 times greater than the factors  $x_1$  (temperature) and  $x_2$  (pressure);
- 4) the quadratic part contains all the terms, it participates in the increase of the resultant with significant values that reverse the order of influence indicated by the linear part; that means it remains as a variation of  $x_1$  (temperature) and  $x_2$  (pressure) to produce a balanced decrease of the result  $y$  (print adhesion) with the variation speed 4.40%, while the factor  $x_3$  (pressing time) leads to the decrease of the result with a speed of 17.60%;
- 5) the interactions  $x_1 \cdot x_2$  follow the direction which the individual variation of each of the variables  $x_1$  and  $x_2$  has upon the resultant  $y$  (print adhesion), so it is positive, but the interactions  $x_2 \cdot x_3$  and  $x_1 \cdot x_3$  diminish the value of the resultant. All interactions have balanced influence.

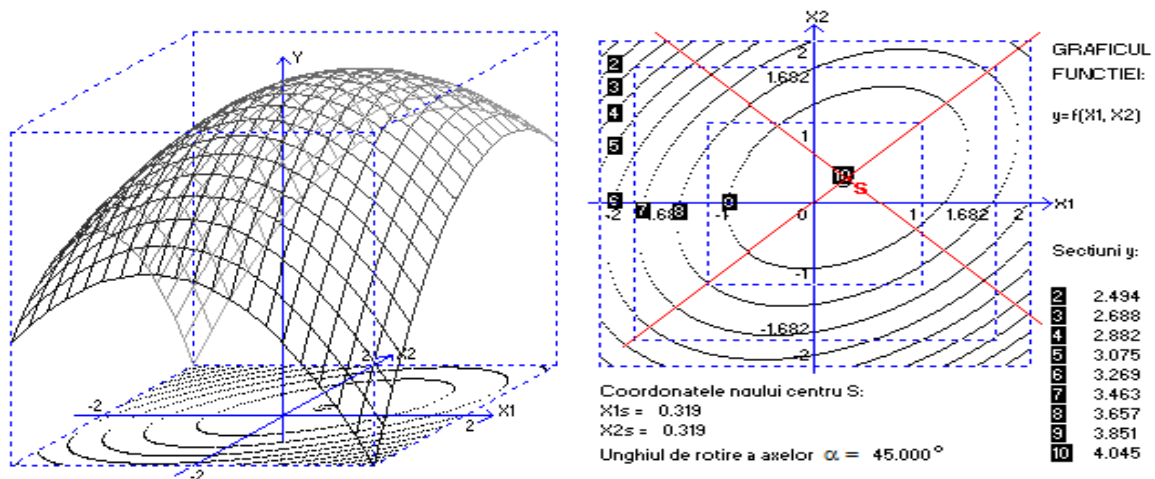
The graphical representations resulted from the OPTEX program, which also served to obtain mathematical models. The graphs are shown in Figures 1 – 3.



**Figure 1.** Variation of print adhesion ( $y$ ) as a function of pressure ( $x_2$ ) and pressing time ( $x_3$ ), (temperature  $x_1 = 0$ ).



**Figure 2.** Variation of adhesion (y) as a function of temperature (x<sub>1</sub>) and pressing time (x<sub>3</sub>), (pressure x<sub>2</sub>=0).



**Figure 3.** Variation of print adhesion (y) as a function of temperature (x<sub>1</sub>) and pressure (x<sub>2</sub>), (pressing time x<sub>3</sub> = 0).

For the independent variables, in order to facilitate the interpretation and realization of the graphs, the coded values were used, and for the isocurves the real values of the result were used. Experimental data were obtained for each resultant variable on the three types of textile material.

The analysis of the graphical representations of the response surface that models the variation of the adhesion of the print as a function of temperature, pressure and pressing time leads to the following conclusions:

- 1) the response surface is of elliptical paraboloid type with extreme maximum point located in the experimental region; the constant level curves obtained by sectioning the response surface with constant level planes are ellipses or ellipse arcs;
- 2) the projection of the top of the paraboloid in the x<sub>1</sub> and x<sub>2</sub> plane represents a maximum point.

The results for the following textile material: fabric from 86% PA + 14% EA and 100% PA fabric, with membrane Gore-Tex are presented below.

Textile material type: **Fabric from 86 % PA+14 % EA**

The regression equation "Eq.(2)".



$$y = 1.996 + 0.319x_1 + 0.343x_2 + 0.759x_3 + 0.125x_1x_2 + .125x_1x_3 + 0.375x_2x_3 + 0.012x_1^2 - 0.165x_2^2 + 0.012x_3^2 \quad (2)$$

Findings from the analysis of the mathematical model:

By checking the significance of the coefficients with the Student test, it is observed that all the coefficients of the equation are significant.

The model proves to be adequate, because the calculated value of the Fisher - Snedecor test is less than the tabulated value of the same test,  $F_{tab} = 5,05$ .

The analysis of the response equation coefficients leads to the following conclusions:

- Linear part of the equation contains all the parameters which shows that their variation significantly influences the resultant;
- Increasing the values of  $x_1$  (temperature),  $x_2$  (pressure) and  $x_3$  (pressing time) leads to increasing of the resultant value with a stronger influence from the factor  $x_3$  (pressing time);
- $x_1$  modifies the answer by 15.98%,  $x_2$  modifies the answer by 17.18%,  $x_3$  modifies the answer by 38.03%, the influence of the factor  $x_3$  (pressing time) is approximately double compared to the factors  $x_1$  (temperature) and  $x_2$  (pressure);
- It participates in the increase of the result with significant values that keep the order of influence indicated by the linear part, only for the factor  $x_2$  there is an influence decrease;
- So, the variation of  $x_1$  (temperature) and  $x_3$  (pressing time) to produce a balanced positive change of the resultant  $y$  with the rate of variation 0.6%, while the factor  $x_2$  (pressure) leads to the decrease of the resultant with a speed of 8.27%;
- Interactions  $x_1 * x_2$ ,  $x_2 * x_3$ ,  $x_1 * x_3$  respect the meaning that the individual variation of each of the variables  $x_1$ ,  $x_2$  and  $x_3$  influences the resultant  $y$  (print adhesion) positively, with a 3 times greater influence from interaction  $x_2 * x_3$ ;

Findings from the analysis of response areas:

The response surface is of ascending ridge type, without extreme points, the constant level curves obtained by sectioning the response surface with constant level planes are parabolic arcs, due to the fact that the center of the surface is far from the center of the experiment area, the curvature radius of the surface in the experimental area is very large and is represented by a tendency of its surface portion to change according to plan.

Textile material type: **Fabric 100 % PA, with membrane Gore- Tex**

The regression equation "Eq.(3)":

$$y = 1.989 + 0.539x_1 + 0.393x_2 + 0.685x_3 + 0.250x_2x_3 + 0.054x_1^2 + 0.054x_2^2 + 0.054x_3^2 \quad (3)$$

Findings from the analysis of the mathematical model:

- The linear part of the equation contains all three parameters, which shows that their change significantly affects the result;
- An increase in the values of  $x_1$  - temperature,  $x_2$  (pressure) and  $x_3$  (pressing time) leads to an increase in the resulting value with a stronger influence of the factor  $x_3$  (pressing time);
- It was found that  $x_1$  changes the answer by 27,1%,  $x_2$  changes the answer by 19,76%,  $x_3$  changes the answer by 34,44%;
- The quadratic part contains all the terms and participates in increasing the result with significant values that support the order of influence indicated by the linear

part; so, variation in  $x_1$  (temperature),  $x_2$  (pressure) and  $x_3$  (pressing time) leads to a balanced positive change in the resultant  $y$  (print adhesion) with a rate of change of 2.71%;

- The interaction  $x_2 * x_3$  takes into account the value that an individual change in each of the variables  $x_2$  and  $x_3$  has for the resulting  $y$  (print adhesion), that is, it is positive.

Findings from the analysis of response areas:

The response surface is of the "minimax" type (hyperbolic paraboloid), the center of the surface is the S point. The S point is outside of the experimental area; the constant level curves for the quasi-stationary domain are hyperbolic; the coefficients of the canonical equation have the same signs, and the constant level curves are balanced in the  $x_2$  and  $x_3$  direction, because the influence of these two variables is balanced.

### Conclusion

Following the analysis of the mathematical models obtained and the response surfaces, it was found that the influence of the pressing time factor is approximately double compared to the temperature and pressure factors. So, time is a key factor that must be initially taken into account when setting technological parameters.

The recommended parameters for each textile material are:

*For the fabric made of 100% polyamide fibers (PA) with Gore-Tex membrane* the recommended technological parameters are: temperature = 185 °C; exerted pressure = 4 atm; exposure time of the part under press = 35 s.

*For the fabric made of 86% polyamide fibers (PA) and 14% elastane (EA)* the recommended technological parameters are: temperature = 150 °C; exerted pressure = 6 atm; exposure time of the part under press = 35 s.

*For knitwear made of 59% polyimide fibers (PA) and 41% elastane (EA)* the recommended technological parameters are: temperature = 150 °C; exerted pressure = 2 atm; exposure time for the part under press = 35 s.

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## SOME PARTICULAR ASPECTS OF THE AUTOMOTIVE INDUSTRY CONNECTORS'

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**Abstract.** Electrical connectors are very sensitive parts in an electronic system. The actual meaning of reliability and the problems associated with determining it, are often not right understood. The paper presents some particular aspects of the automotive industry connectors' i.e. fretting, fretting corrosion prevention, aluminium connections. The performance factors governed by the operating conditions and design-technology factors determined by the manufacturing characteristics of a contact unit were analyzed.

**Keywords:** *Connector failures, microsensors and micromechatronic actuators, reliability, thick film technology, fretting, fretting corrosion, connector standards.*

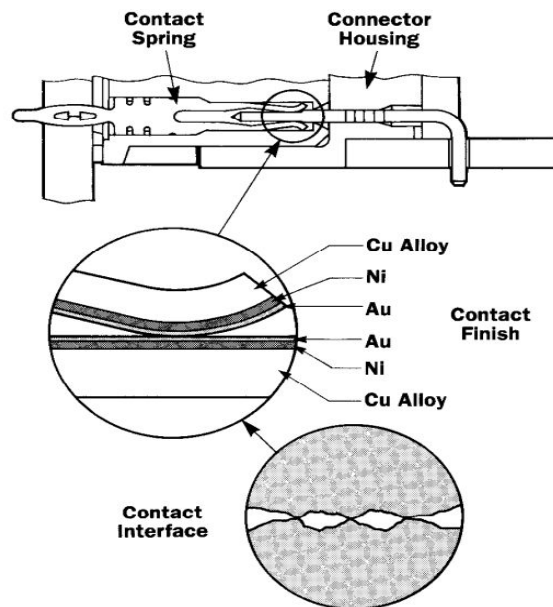
**Rezumat.** Conectoarele electrice sunt părți foarte sensibile într-un sistem electronic. Semnificația reală a fiabilității și problemele asociate cu determinarea acesteia adesea nu sunt înțelese corect. Lucrarea prezintă câteva aspecte particulare ale conectoarelor din industria auto și anume fretting, prevenirea coroziunii prin fretting, conexiuni din aluminiu. Au fost analizați factorii de performanță guvernați de condițiile de funcționare și factorii de proiectare-tehnologie determinați de caracteristicile de fabricație ale unei unități de contact.

**Cuvinte cheie:** *Defecțiuni ale conectoarelor, senzori și actuatori micromecatronics, fiabilitate, tehnologie cu peliculă groasă, fretting, coroziune prin fretting, standarde pentru conectoare.*

### Introduction

Electrical connectors are a prerequisite for electrical and electronic connections. Basically the connector is a component which enables systems to be optimal used in the electrical energy transmission and the electronic and optical signal transmission. Electrical connectors are very sensitive parts in an electronic system [1]. The requirements specified for connector contacts in terms of wear resistance, wiping efficiency, corrosion resistance and mechanical stability are more or less stringent, depending on the intended use and environmental exposure. Contact between two cable terminals only occurs at small discrete spots where the asperities of the two surfaces meet [2].

Electric connectors (Figure 1) are an indispensable component of electronic circuits. Although connectors broadly fall into one of three categories: (i) wire / cable-to-wire/cable; (ii) wire / cable-to-board; and (iii) board-to-board connectors, precise definitions have not yet been established [3].



**Figure 1.** Typical connector indicating the major structural components (after [3]).

### Smart car connectivity

Cars are in motion, roads are uneven, and this generates mechanical harmonics that could cause connectors to disengage over time. Currently, Smart Car connectivity occurs in two ways. Embedded cars utilise a built-in radio and antenna connecting to local cellular networks, while tethered cars use a wireless connected device, typically a cell phone, to provide the data connectivity [4]. Cameras are the optical sensor portion of the sensor suite required for higher levels of autonomy. Currently, most cameras are used for vision systems and basic safety features such as parking assistance. As future cameras are designed and deployed with a requirement for higher data rates due to high resolutions like 4K or stereo image streams, there will be a need for the connectors and cable to support greater than 6 GHz. The other significant growth area driven by the development of autonomous vehicles is data communication: vehicle to vehicle and vehicle to infrastructure.

Autonomous capability requires vast and comprehensive information to enable robust Artificial Intelligence (AI) decisions. The cameras and other sensors will be supplemented by large streams of data from wireless sources. Real time information from other vehicles and infrastructure will supply the AI module with the latest critical information from nearby 5G devices and the cloud [5]. The vehicle accesses these data streams with multiple antennas either dispersed or consolidated into smart antennas. Smart antennas reduce the amount of cabling in the vehicle, further reducing cost and weight, but add a complexity in connecting the antenna signals to the processing boards.

The automotive landscape is rapidly transforming, as autonomous systems, electric drive trains, and tech-enhanced interiors become part of the car experience across makers and price points. Future car technologies are arriving now, thanks to precision automotive connectors. These must be optimized to withstand the automotive harsh environments, which include shock, vibration, temperature extremes, moisture, and ingress by dirt and other particulates. High speed, high frequency connectors must handle significant amounts of in-vehicle data as well as transit information to data centres and cloud computer facilities [6]. Connectors need to be accessible, easy to handle, and easy to swap out in the event of damage.

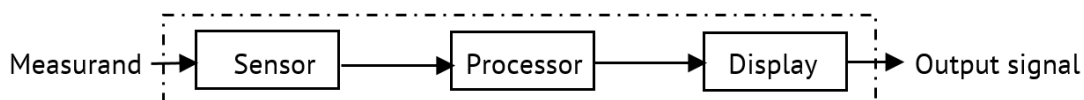
Connectors must be able support a wide variety of sensors types and rapidly and reliable transfer large amounts of data. Even as connectors become smaller and lighter, high-quality contacts and secure locking features remain critical. Connectors involved in charging systems must be ruggedized to endure thousands of charging cycles [7].

Connectors are indispensable for safe data and reliable power transmission in automobiles. In the networking of tomorrow's production, connection technology is the main interface between machines, controls and data processing systems. Reliable plug connections in automotive and industrial applications, and form the basis for functionality, easy handling and reliability of the expenditure to be fulfilled.

The digitized wiring system is one of the most important function carriers within autonomous automobiles as well as automation systems. The products are differentiated not only by price, but in particular by attributes and additional benefits such as technical reliability and innovation, ease of use and compact design [8]. Connectors are evaluated for a number of cycles from a single use to several thousand.

New connection technologies and integration techniques are being researched in order to implement intelligent connectors with sensors and actuators [9]. Typical failures, due to friction corrosion or chemical corrosion, have short notice times and still know how to lead to failure of important systems. An integrated monitoring of the current connection quality through integrated, miniaturized electronic sensor systems could help.

Improving products, finding out technical connections, developing new technologies and then vividly passing on these findings to the next generation of engineers - this is what drives today.

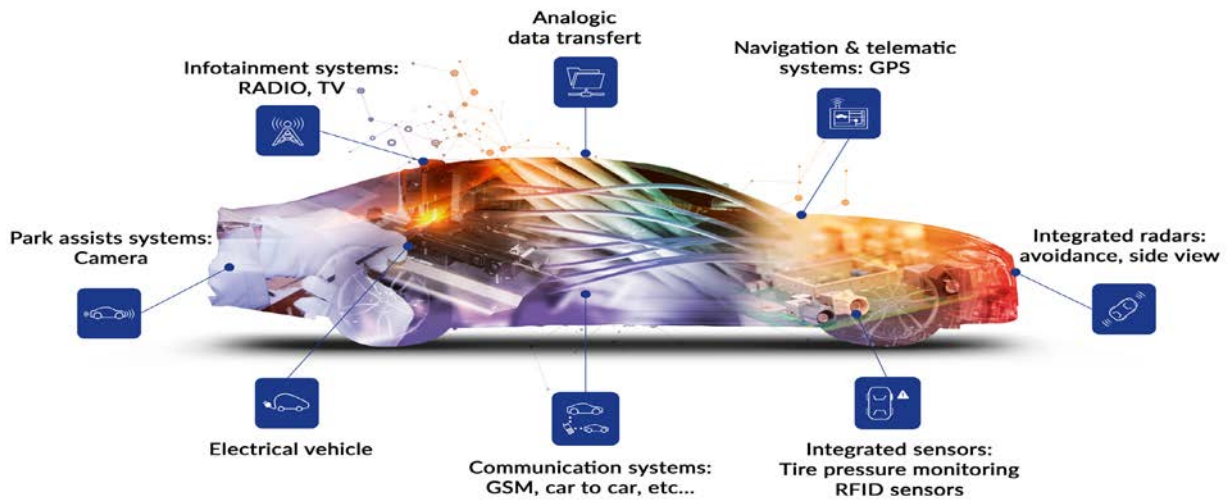


**Figure 2.** From measuring to output signal.

In addition to the pressure from emission regulations, a political and regulatory trend towards the promotion of electric vehicles is also emerging internationally. Recent reports speak of a ban on vehicles with combustion engine in Norway from 2025 and in France and Great Britain from 2040. To what extent these plans will be implemented, remains to be seen. For this reason, the strategies of major automobile manufacturers focus on the development of electric drives. Car manufacturers are currently reacting to the trend towards electrified vehicles with a development offensive. To ensure that all components are electrically safe and separable from each other, various plug connections are used in the low-voltage and high-voltage range.

Through vibration tests, contact resistance measurements and SEM images, it was possible to find relationships between sliding distance, number of oscillations and electrical resistance increase [10]. In vehicle construction, a fatigue strength analysis includes not only the validation of "classic", time-varying operational stresses, but also the consideration of special events when used as intended (e.g. slow obstacle crossing of potholes or similar), abuse events (e.g. fast obstacle crossing), creep or wear (e.g. joint wear of chassis components).

From material development and simulation of vehicle bodies known multi-level principles are to be further developed, transferred to the operational stability analysis of high-voltage accumulators and plug contacts in an interdisciplinary manner and oriented to the multi-scale structure of the components as well as to the existing stress situations and damage mechanisms [11].

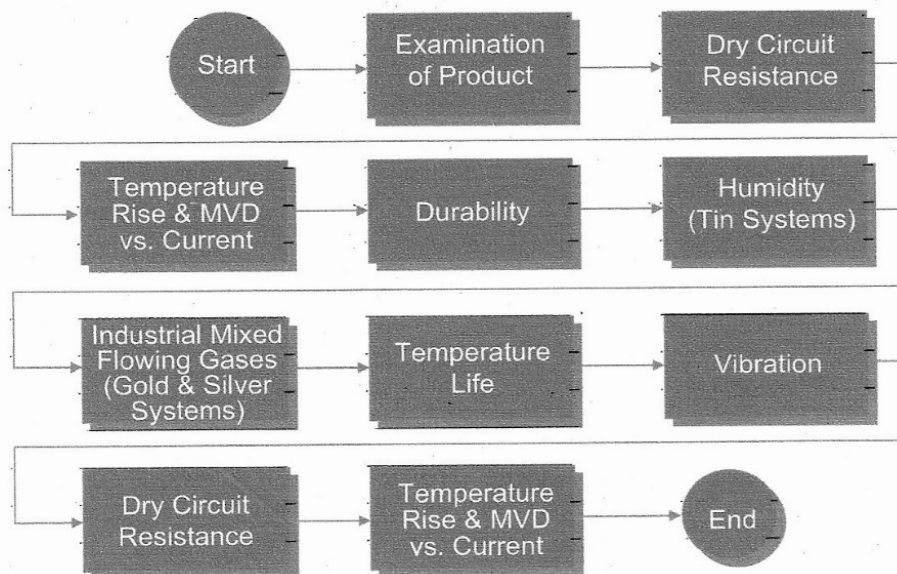


**Figure 3.** Some examples of connectors utilized in automotive industry [after 10].

Optical measurement methods are usually ruled out in practice due to excessive complexity, lack of reliability for measurements in the engine compartment and poor accessibility of components and measuring points.

### Reliability aspects

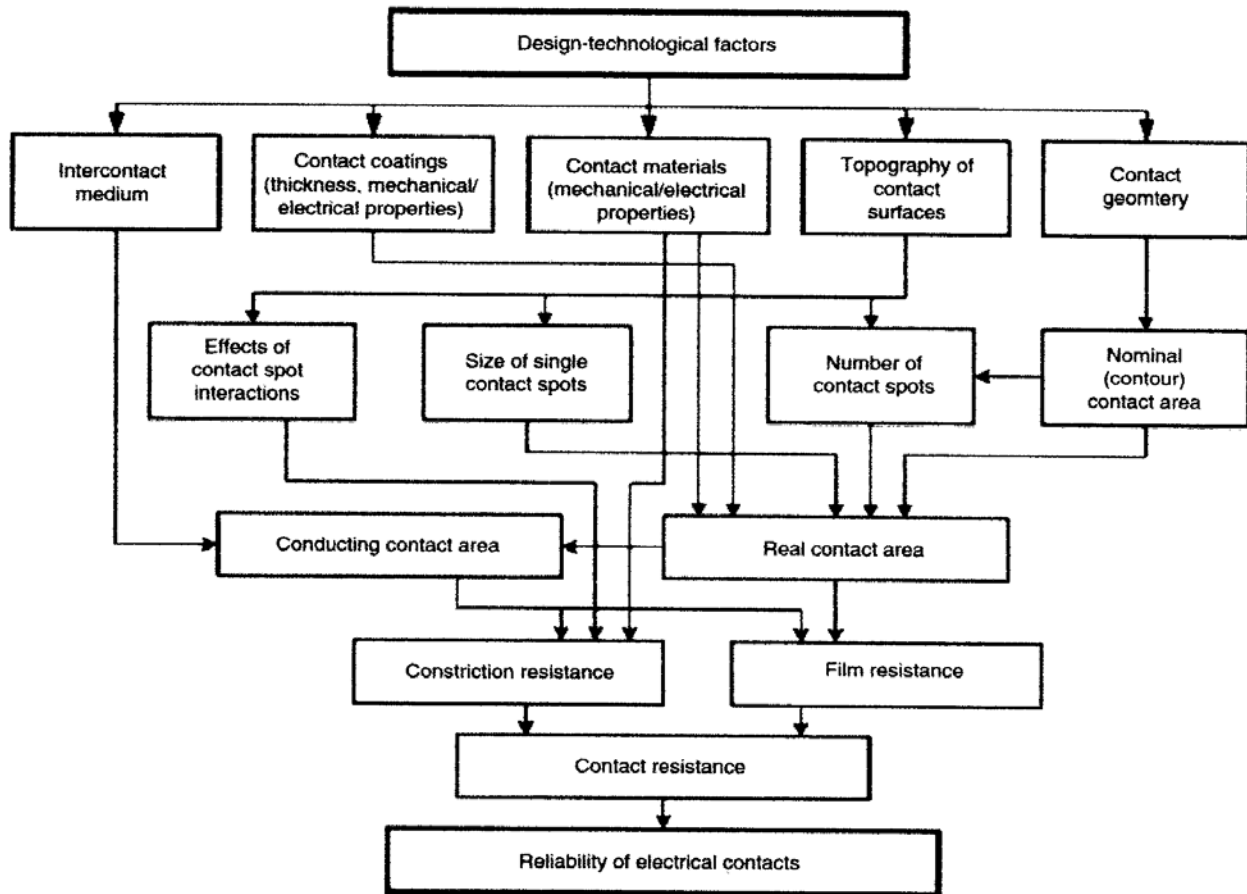
There are two aspects to ensuring connector reliability: building reliability into the connector through materials and design choices, and assessing that reliable performance has been realized [8, 12].



**Figure 4.** Reliability assessment testing.

Today's contact families using high-performance alloys (e.g. CuNiSi) are considerably more current-carrying than previous systems.

In the so-called reliability concept of measurement, securities and valuations are always determined on the basis of probabilities and calculated scatters [11]. The reliability concept cannot only be to the fatigue-resistant design, but also to the operation-resistant design with damage calculations.



**Figure 5.** Effect of performance factors on the reliability of electrical contacts (after [11]).

### Factors affecting reliability

The variety of the factors can be conventionally divided into (1) the performance factors governed by the operating conditions and (2) the design-technological factors determined by the fabrication characteristics of a contact unit [13]. The performance factors (parameters) are divided basically into two groups: internal and external (Figure 5).

The performance factors affect the properties of contact materials and surface films, the occurrence of physical and chemical processes in the contact zone, wear particle formation thus influencing the state of the interface and, finally, the contact resistance and reliability of electrical contacts [14 - 16].

*Failure causes and mechanisms:* **1.** Mating/unmating cycling increases oxidation susceptibility by erosion/corrosion of protected layer. **2.** Temperature. • The effect of temperature in connector is stress relaxation. • Stress relaxation results in loss of the normal force, which in turns increases the contact resistance. • Nickel oxidation. **3.** Humidity. • The major effect of humidity on metal contacts is possible corrosion. • A decrease in contact resistance occurs with humidification and an increase in resistance occurs with dehumidification [19].

There were many researchers who among the years were investigating this phenomenon and associated issues giving the foundations of science, which is today called "tribology". The fretting nowadays is a term, which is used in reference to the situation where two bodies staying in contact experience a small relative movement (Figure 9) [Eden et al.] [Tomlinson].



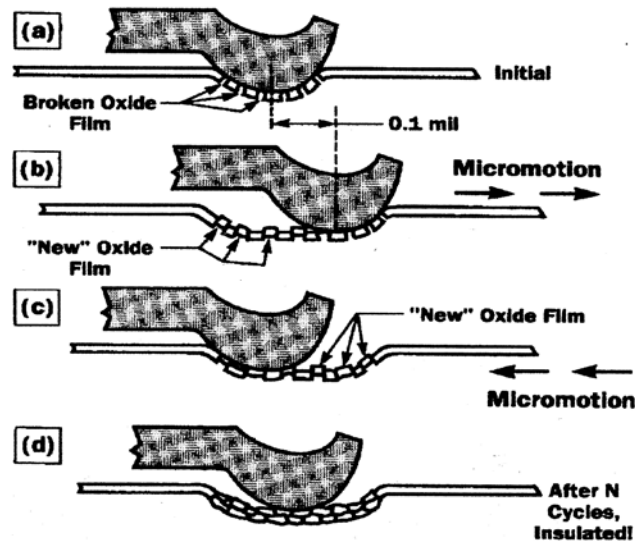


Figure 6. Schematic illustrations of the mechanisms of fretting.

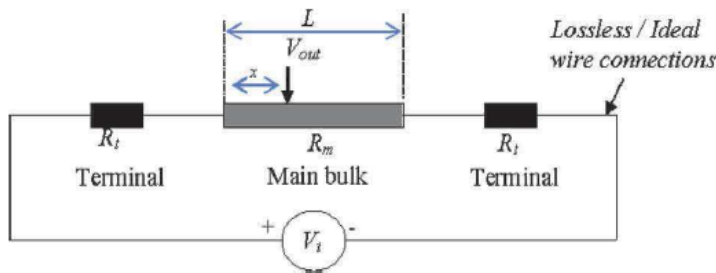


Figure 7. Electrical equivalent of the thick film sensor.

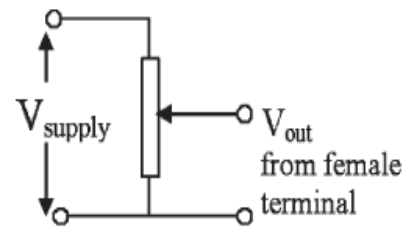


Figure 8. Schematic representation of sensor's working principle.

**Fretting**

Fretting as a phenomenon of the wear of the surface of contacting bodies was first observed by Eden. He confirmed the presence of iron oxide debris between the two samples subjected to a relative motion. It is Tomlinson who is considered the father of the definition and the term "fretting".

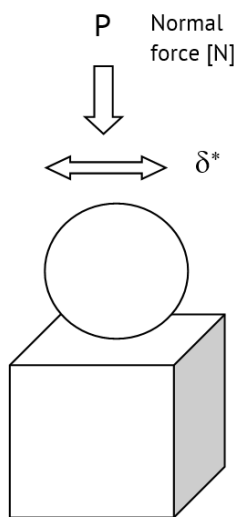


Figure 9. Illustration of the sphere/plane contact subjected to the fretting loadings.  $\delta^*$  - displacement amplitude [ $\mu\text{m}$ ].

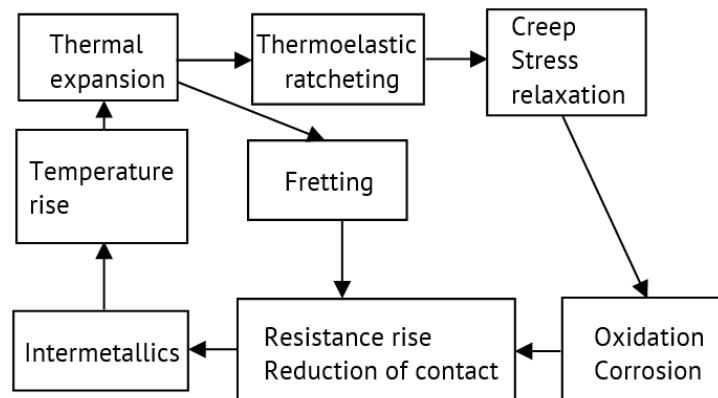


Figure 10. Schematic of degradation mechanisms in aluminum connections.

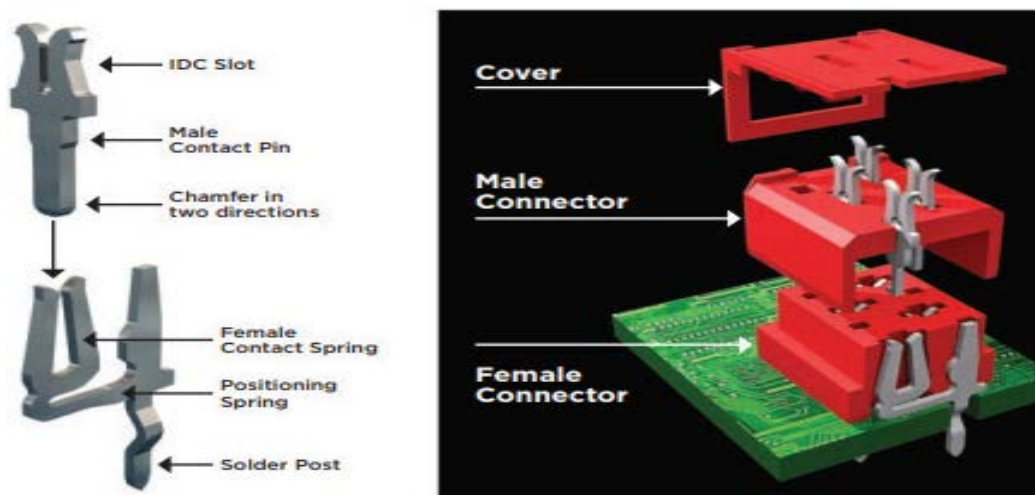
The three basic reference contact geometries that are usually used are (1) cylinder/plane, (2) plane/plane, and (3) sphere/plane. Although the plane/plane geometry is the easiest, from a mechanical point of view, the discontinuity of the pressure on the border of the contact makes the analysis of the contact very complicated. To simplify the analysis, two remaining geometries are used to investigate the fretting phenomenon. The simplicity of the contact mechanics and ease of application make them the most popular configurations for research on fretting and contact mechanics. The cylinder/plane geometry describes the 2D linear contact situation. The distribution of the stress and elastic deformations are very well described by the theory of Hertz. The cylinder/plane geometry is often used in the research on the cracking and crack propagation since it enables two-dimensional approach which can be modelled by the finite element method [Hertz][Proudhon].

The complexity of failure mechanisms in aluminum power connections is best depicted in the course of a cycle, as shown in Figure 10.

### Fretting corrosion prevention

Fretting is wear or corrosive damage responding to the roughness of contact surfaces. This damage results under load and in the presence of repetitive surface motion conditions. Vibration can also cause a fretting condition. The traditional failure mode in tin-plated connections is fretting corrosion [21 - 23]. The Micro-MaTch connector assists in preventing such corrosion. Because of the female part's additional positioning spring, the Micro-MaTch connector absorbs relative vibration and thermal-expansion movements between male and female contacts. This configuration of connectors creates an airtight connection, as it prevents contact spot movements (Figure 11).

The Micro-MaTch contact spring system is resistant to fretting corrosion. In this system, the positioning spring compensates positional tolerances and provides the tin-plated contact system's high contact force [6].



**Figure 11.** The connector socket has a contact spring system that acts to create a socket with fretting-corrosion resistance [6].

### Conclusions

In order to reduce wear and corrosive damage, it is necessary to test and operate them according to the connectors standards:

- IEC 61586 provides the most extensive reliability testing protocol.
- There is a basis of agreement to develop standard reliability testing protocols.

- EIA 364F: Electrical Connector/Socket Test Procedures Including Environmental Classifications.
- EIA 364-1000: Environmental Test Methodology for Assessing the Performance.
- ISO/IEC TR 29106: Introduction to MICE Environmental Classification.
- IEC 61586-TS: Estimation of the Reliability of Electrical Connectors.

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CZU 623.09:004.932



## METHODS OF TARGET RECOGNITION BASED ON CENTRAL IMAGE CHORD TRANSFORMATION

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**Abstract.** In the article the analysis of different approaches to invariant target recognition was made, such as based on the support vector machines, deep learning techniques, neural networks, generation of moment features, etc. It was determined that one of the perspectives approaches in target recognition suppose the use of the central and logarithmic central image chords transformations. There have been described the new methods of the target recognition, based on the central image chords transformation. Tasks of target recognition were formulated. New 4 methods of target recognition were described. It is presented the comparison of the different target's recognition methods regarding the processing stages number, realized operations, target's image normalization's operation, the operations realized in parallel, kind of the target's scale and rotation determination sequence, target's rotation determination approach.

**Keywords:** *target, chord, transformation, recognition, processing stage, operation, spectrum.*

**Rezumat.** În articol este prezentată analiza diferitelor abordări ale recunoașterii invariante a țintei, cum ar fi pe baza mașinilor vectoriale de suport, tehnici de învățare profundă, rețele neuronale, generarea de caracteristici ale momentelor ș.a. A fost determinat că una dintre direcțiile importante în recunoașterea automată a țintei se bazează pe transformări centrale și logaritmice centrale ale coardelor de imagine. Sunt descrise noile metode de recunoaștere a țintei, bazate pe transformarea centrală a coardelor imaginii. Sunt formulate sarcinile de recunoaștere a țintei. Sunt descrise 4 metode noi de recunoaștere a țintei. Este dată compararea diferitelor metode de recunoaștere a țintei în ceea ce privește nr de etape de procesare, de operațiuni realizate, de operațiuni de normalizare a imaginii țintei, de operațiuni realizate în paralel, privind secvența de determinare a scării și rotației, abordarea determinării rotației țintei.

**Cuvinte cheie:** *țintă, coardă, transformare, recunoaștere, etapă de procesare, operație, spectru.*

### 1. Introduction

Invariant target recognition (ITR) is one of the important fields in military and civil applications, which suppose the real-time target classification independent of his position into the plane, rotation, scale, etc. In the articles [1 - 3] the approaches based on using the

Support Vector Machines (SVM) in ITR are described. Another direction supposes the deep learning techniques used, which have been an important yet challenging research field in computer vision. In the research [4], a deep learning-based method was applied and a conditional random field is used to generate finer details. In the articles [5, 6] the ITR systems using the neural networks are described. The ITR based on the target's moment features is described in the articles [7, 8]. Unfortunately, the described approaches are complex in realization and need sufficient processing time.

One of the perspective approaches supposes the realization of the target's image chord transformation [9, 10]. The present article consists of the results of elaboration and investigation of the new target recognition methods, based on the central image chords transformation. In section 2 there are formulated the tasks of target recognition. In sections 3÷6 there are described the new 4 methods of target recognition. In section 7 it is presented the comparison of the different target's recognition methods regarding the processing stages, realized operations, target's image normalization's operation, the operations realized in parallel, kind of the target's scale and rotation determination sequence, target's rotation determination approach.

## 2. Tasks of target recognition and the operations realized in the target recognition methods

Let the target be described via a continuous brightness function  $P(x,y)$ . Let under the influence of some distorting function DF, in the target's image can be introduced the noise and all points of the areas of  $P(x,y)$  determination are changed by a certain law:

$$P(x,y) \rightarrow DF[P(x,y)] = P'(x',y').$$

In the presence of the shifts, angular rotation and scale distortions, the law of changes can be described by equations of a 4-parametric group of transformations [11]:

$$x'=F_1[x,y,DF(x,y)]=\{e_1[x\cos(e_2)-y\sin(e_2)]+e_3\}, y'=F_2[x,y,DF(x,y)]=\{e_1[x\sin(e_2)+y\cos(e_2)]+e_4\}.$$

Here  $e_1$  is a homothetics parameter, describing the scale change of the target's image;  $e_2$  - parameter characterizing rotation of the target in the OXY plane;  $e_3, e_4$  - are the target's shifts of the in the plane relative to its reference position. In this case, the function  $P'(x',y')$  can be represented as:

$$P'(x',y') = P(x+e_3,y+e_4,e_1,e_2).$$

Let describe the tasks of a target recognition as follows: target's image capture, classification of the target; target's space parameters determination - target's image scale  $e_1$ , his angular rotation  $e_2$ , and the target's in the plane position  $e_3$  and  $e_4$ . These data will permit the organization of effective target tracking.

In the target recognition method described below, will be realized the next operations: PP - input target's image preprocessing; F - Fourier transform operation; P - target's position in plane determination (parameters  $e_3, e_4$ ); N - normalization of the target's image (centering on parameters  $e_3, e_4$ ); N1 - target's image normalization on  $e_1$  and conversion to a polar coordinate system; N2 - target's image conversion to log-polar coordinate system; N3 - normalization of the target's image (centering on parameters  $e_3, e_4$ ) via Fourier spectrum calculation; N4 - normalization of the target's image (centering on parameters  $e_3, e_4$ ) and conversion to a log-polar coordinate system; N5 - target's image spectrum normalization on  $e_1$  and conversion to a polar coordinate system; N6 - normalization of the target's image (centering on parameters  $e_1, e_2$ ) and conversion to a log-polar coordinate system; T - chord transformation of the centered target's image; CT1 - chord transformation of the target's

image Fourier spectrum; C – classification of the target; S – scale  $e_1$  of the target determination; R – rotation  $e_2$  of the target determination; S, R – target's scale  $e_1$  and rotation  $e_2$  determination in one step.

### 3. Method TRM1 of target recognition

The method TRM1 suppose the next sequence of operations: PP-F-P-N-CT-C-S-N1-R. Following this method, **at the first stage**, the input target's image is preprocessed. The target's image is enhanced, noise is removed, etc.

$$P'(x',y') \rightarrow P(x',y')=P(x,y,e_1,e_2,e_3,e_4), \quad (3.1)$$

**At the second stage**, the position of the target in the plane (parameters  $e_3, e_4$ ) is calculated. In parallel, the target's image Fourier spectrum is calculated:

$$P(x',y') \rightarrow |FT\{P(x',y')\}|^2=P(x'_1,y'_1)=P(x_1,y_1,e_1,e_2), \quad (3.2)$$

where  $FT\{\dots\}$  is the Fourier transform operation. The maximum frequency  $f_m$  of the Fourier spectrum  $P(x'_1, y'_1)$  and the target's image  $P(x',y')$  complexity SL [12] are determined.

The obtained function  $P(x_1,y_1,e_1,e_2)$  will be not influenced by the parameters  $e_3, e_4$ , due to the properties of the Fourier spectrum [11].

**On the third stage**, based on the parameters  $e_3, e_4$ , and SL, the function  $P(x',y')$  is centered:

$$P(x',y')=P(x+e_3,y+e_4,e_1,e_2)\rightarrow P(x'_2,y'_2)=P(x_2,y_2,e_1,e_2), \quad (3.3)$$

where  $x_2=x-e_3, y_2=y-e_4$ .

**On the fourth stage** will be realized Central Image Chord Transformation (CICT) [10]:

$$P(x'_2,y'_2)\rightarrow T\{P(x'_2,y'_2)\}=P(x'_3,y'_3), \quad (3.4)$$

where  $T\{\dots\}$  – the operation of CICT. Based on the function  $P(x'_3,y'_3)$ , will be formed a vector  $\mathbf{v}$  of the target's features [11].

**At the fifth stage**, the target recognition will be made at the processing of the vector  $\mathbf{v}$ . The classification algorithm is based on the Fisher criterion [11] using the combination of the target's features and forming a linear discrimination function for reference target's images of different kinds at arbitrary rotations, scale changes, etc.

**On the sixth stage**, the target's scale  $e_1$  is determined based on the expression:

$$e_1=f_{ms}/f_m, \quad (3.5)$$

where  $f_{ms}$  is the Fourier spectrum's maximum frequency of the standard target, the class of which was determined on the previous stage.

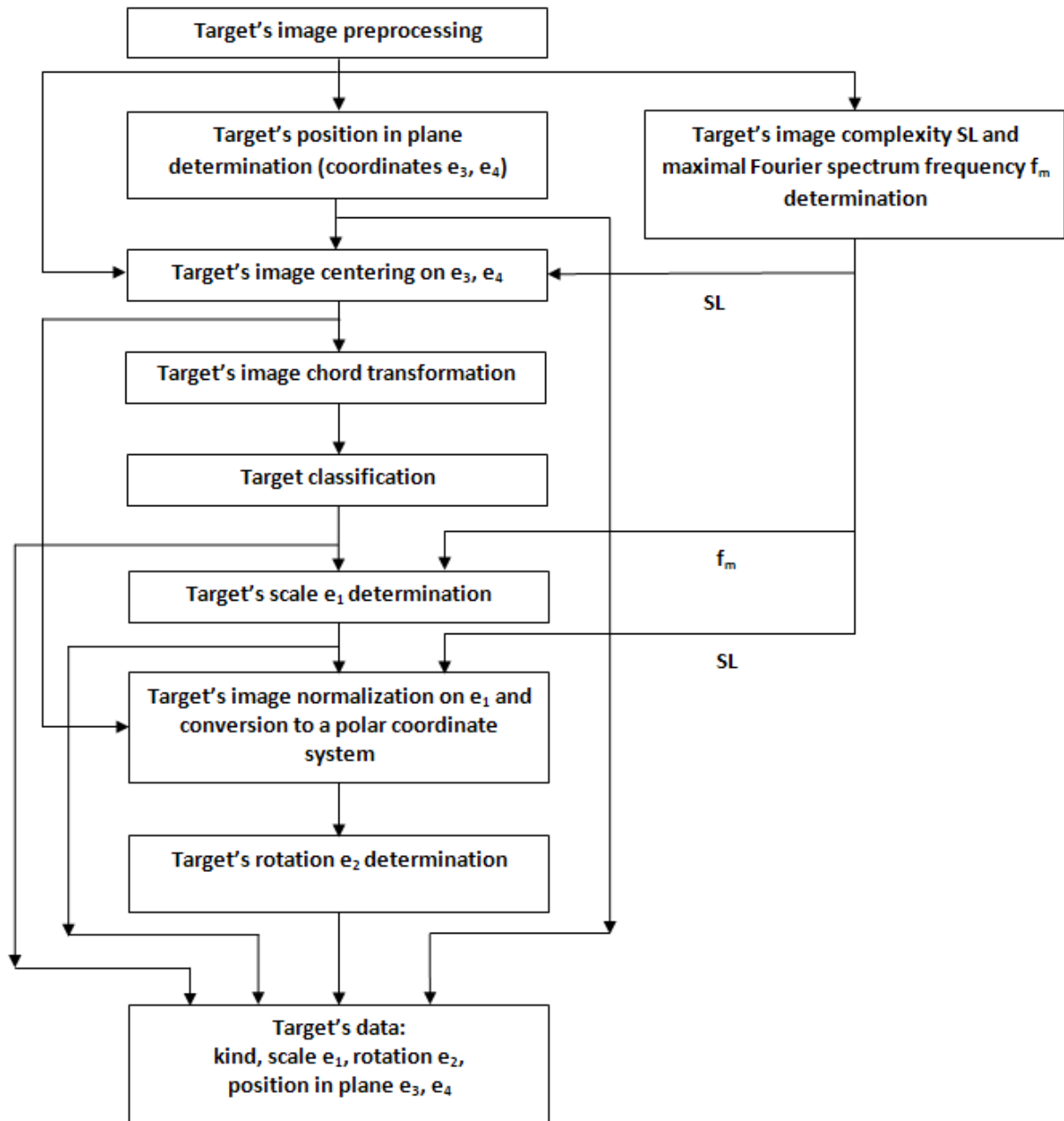
**On the seventh stage**, the function  $P(x'_2,y'_2)$  is normalized on  $e_1$  and transformed to a polar coordinate system:

$$P(x'_2,y'_2)=P(x_2,y_2,e_1,e_2)\rightarrow P(x'_4,y'_4)=P[x_4+x_{40}(e_2),y_4], \quad (3.6)$$

where  $x'_4=\arctg(y_2/x_2), y'_4=[(x_2^2+y_2^2)^{1/2}]/e_1$ .

By this operation, the effect of the target's rotation (parameter  $e_2$ ) is reduced to a shift of the function  $P(x'_4,y'_4)$  along the axis  $x_4$ .

**At the eighth stage**, the parameter value  $e_2$  is calculated based on component  $x_{40}(e_2)$  by phase extraction [13].



**Figure 1.** The method TRM1 of target recognition.

As a result, it will be obtained the data regarding the kind of the target, his scale (parameter  $e_1$ ), rotation (parameter  $e_2$ ), and position in the plane (parameters  $e_3, e_4$ ).

#### 4. Method TRM2 of target recognition

The method TRM2 of target recognition use next operations: PP-F-P-N-CT-C-N2-S,R (Figure 2) By this method, the data processing on stages 1 - 5 is the same as at the method M1.

**At the sixth stage**, the centered target's image will be converted to the log-polar coordinate system:

$$P(x'_2, y'_2) = P(x_2, y_2, e_1, e_2) \rightarrow P(x'_4, y'_4) = P[x_4 + x_{40}(e_1), y_4 + y_{40}(e_2)], \quad (4.1)$$

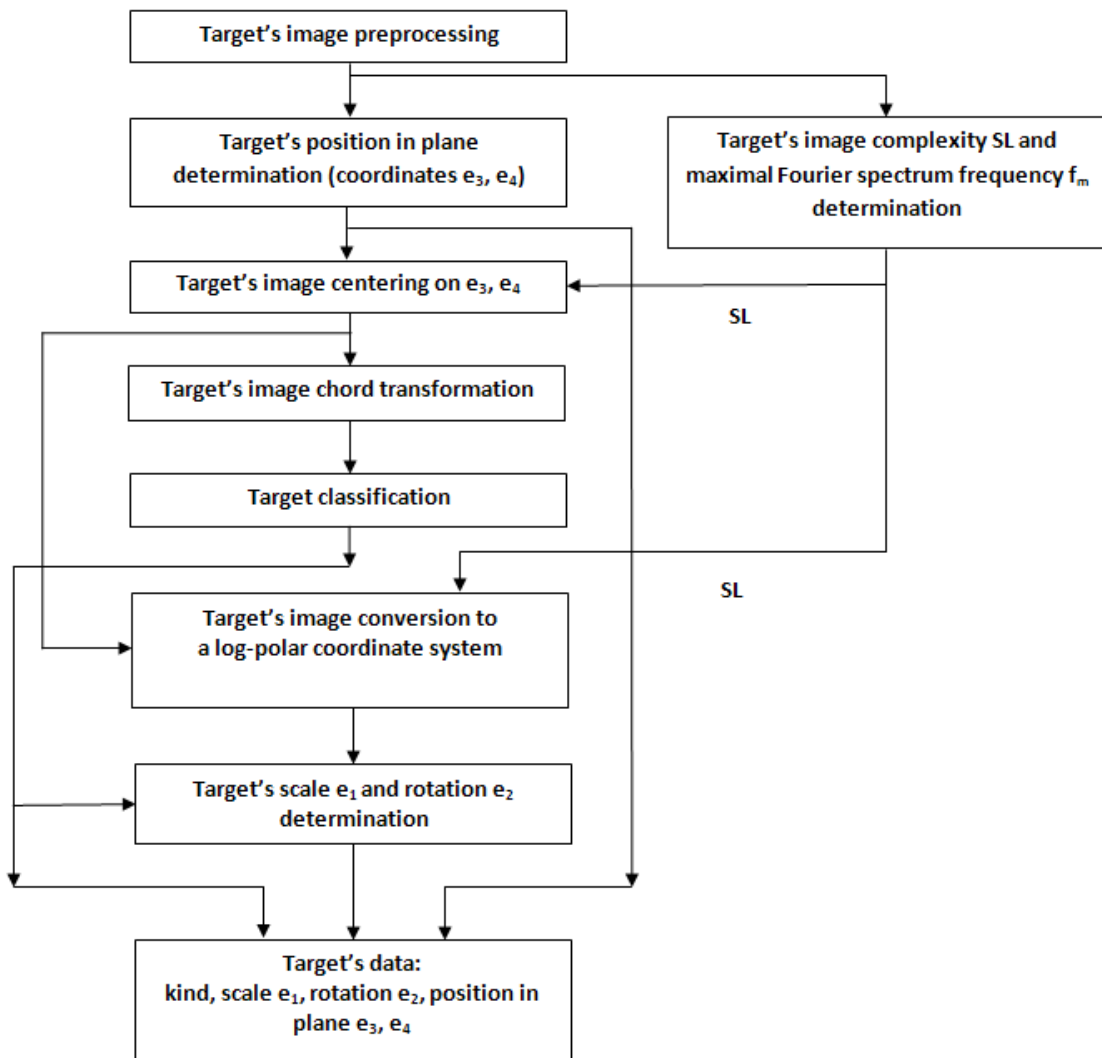
where  $x_4 = \arctg(y_2/x_2)$ ,  $y_4 = \ln[(x_2^2 + y_2^2)]/2$ , and  $x_{40}(e_1)$ ,  $y_{40}(e_2)$  are the constants, determined by parameters  $e_1$  and  $e_2$  respectively.

Wherein, the effects of the target scaling (parameter  $e_1$ ) and rotation (parameter  $e_2$ ) are reduced to shifts of the function  $P(x'_4, y'_4)$  along the axis  $x_4$  and  $y_4$  respectively.

**On the final, seventh stage,** the target's scale  $e_1$  and rotation  $e_2$  determination will take place based on the operation of correlation, realized between the target's function  $P(x'_4, y'_4)$  and standard target's function  $P_s(x_4, y_4)$ , the class of which was established on the stage of classification:

$$U(x, y) = \max\{\iint P(x'_4, y'_4)P_s(x_4, y_4) dx_4 dy_4\}. \quad (4.2)$$

In comparison with method TRM1, in the method TRM2 is using another kind of the target's image conversion - to the log-polar coordinate system and the parameters of scale  $e_1$  and rotation  $e_2$  are determined in one stage only using the correlation approach.



**Figure 2.** The method TRM2 of target recognition.

### 5. Method TRM3 of target recognition

The method TRM3 of target recognition suppose the next operations: PP-P,N3-CT1-C-N4-S,R (Figure 3) The first stage of method TRM3 is the same as in the previous methods.

**At the second stage,** the target's position in the plane (parameters  $e_3, e_4$ ) is calculated and the Fourier spectrum of the target's image is obtained:

$$P(x', y') = P(x+e_3, y+e_4, e_1, e_2) \rightarrow |\text{FT}\{P(x', y')\}|^2 = P(x'_1, y'_1) = P(x_1, y_1, e_1, e_2) \quad (5.1)$$

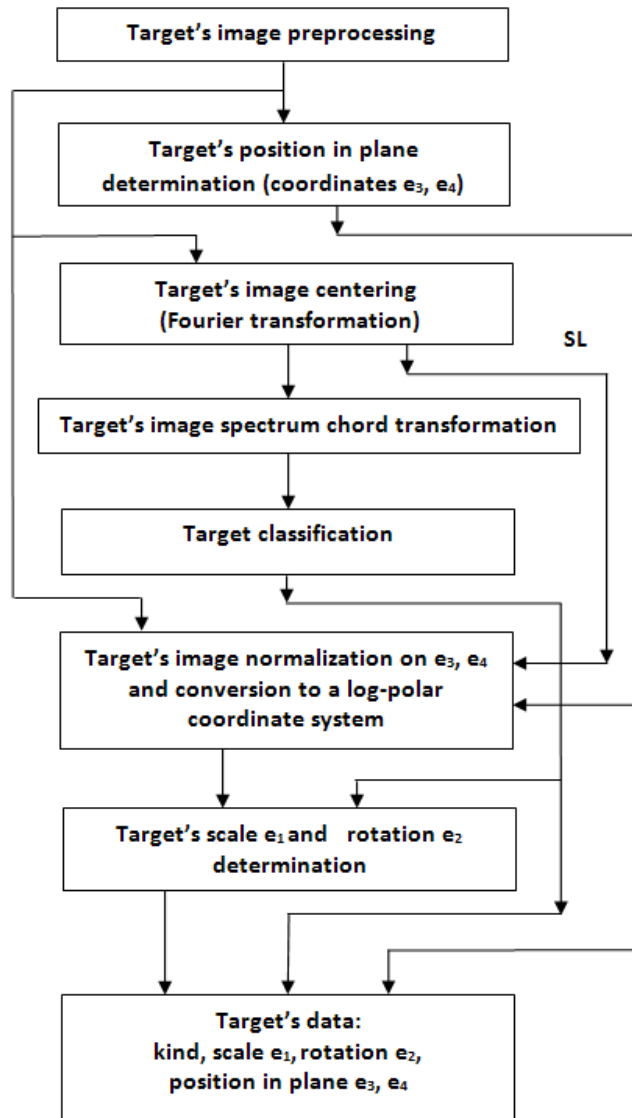


By this operation, the target's image is centered on parameters  $e_3$  and  $e_4$ . The complexity SL of the function  $P(x',y')$  is determined.

**On the third stage** will be realized Central Image Chord Transformation (CICT) of the function  $P(x'_1,y'_1)$ :

$$P(x'_1,y'_1) \rightarrow T\{P(x'_1,y'_1)\} = P(x'_2,y'_2), \quad (5.2)$$

where  $T\{\dots\}$  – the operation of CICT. The vector  $\mathbf{v}$  of the target's features will be formed.



**Figure 3.** The method TRM3 of target recognition.

At the same time, the function  $P(x',y')$  is centered based on the parameters  $e_3$ ,  $e_4$ , and parameter SL, and is converted to the log-polar coordinate system:

$$P(x',y') = P(x+e_3, y+e_4, e_1, e_2) \rightarrow P(x'_3, y'_3) = P[x_3 + x_{30}(e_2), y_3 + y_{30}(e_1)], \quad (5.3)$$

where  $x'_3 = \arctg(y''/x'')$ ,  $y'_3 = \ln[(x'')^2 + (y'')^2]/2$ , and  $x'' = x' - e_3$ ,  $y'' = y' - e_4$ .

So, the function  $P(x'_3, y'_3)$  will not be influenced by parameters  $e_3$ ,  $e_4$ . The influence of the parameters  $e_1$  and  $e_2$  will be reduced to the shifts of the function  $P(x'_3, y'_3)$  on coordinates

$x'_3, y'_3$ . The values  $x_{30}(e_2)$  and  $y_{30}(e_1)$  are the constants determined by parameters  $e_2$  and  $e_1$  respectively.

**At the fourth stage**, the target recognition based on the processing of the vector  $\mathbf{v}$  will be made.

**On the fifth stage**, the target's scale  $e_1$  and rotation  $e_2$  are calculated based on the target's kind determined previously and calculation of the correlation function:

$$U(x_4, y_4) = \max\{\iint P(x'_3, y'_3)P_s(x_3, y_3)dx_3dy_3\}, \quad (5.4)$$

where  $P_s(x_3, y_3)$  is the target's standard function.

The main differences of the method TRM3 in comparison with previous methods consist in the fact, that the operations of chord transformation and classification are based on the target's image Fourier spectrum processing on stages 3 and 4, and in the realization of the combined operation of the target's image normalization on the parameters  $e_3$  and  $e_4$  and conversion to the log-polar coordinate system (stage 3).

## 6. Method TRM4 of target recognition

The method TRM4 of target recognition suppose the realization of the next set of operations: PP-N4-CT1-C-S-N2-R-N6-P (Figure 4) The first stage of the method TRM4 is the same as in the previous methods.

**At the second stage**, the Fourier spectrum of the target's image is formed:

$$P(x', y') = P(x+e_3, y+e_4, e_1, e_2) \rightarrow |\text{FT}\{P(x', y')\}|^2 = P(x'_1, y'_1) = P(x_1, y_1, e_1, e_2), \quad (6.1)$$

where  $\text{FT}\{\dots\}$  - is Fourier transform operation.

As a result of this operation, the target's image is centered on parameters  $e_3$  and  $e_4$ . Based on the function  $P(x'_1, y'_1)$ , the maximum frequency  $f_m$  and the of the target's image  $P(x', y')$  complexity  $SL$  are determined.

**On the third stage** will be realized Central Image Chord Transformation of the function  $P(x'_1, y'_1)$ :

$$P(x'_1, y'_1) \rightarrow T\{P(x'_1, y'_1)\} = P(x'_2, y'_2), \quad (6.2)$$

The vector  $\mathbf{v}$  of features will be calculated based on the function  $P(x'_2, y'_2)$ .

**At the fourth stage**, the target recognition will be made based on the vector  $\mathbf{v}$  processing.

**On the fifth stage**, the target's scale  $e_1$  is determined as

$$e_1 = f_{ms}/f_m, \quad (6.3)$$

where  $f_{ms}$  is the Fourier spectrum's maximum frequency of the standard target, the class of which was determined on the previous stage.

**On the sixth stage**, the target's image spectrum will be normalized on scale  $e_1$  and transformed to a polar coordinate system:

$$P(x'_1, y'_1) = P(x_1, y_1, e_1, e_2) \rightarrow P(x'_3, y'_3) = P[x_3 + x_{30}(e_2), y_3], \quad (6.4)$$

where  $x_3 = \arctg(y'_1/x'_1)$ ,  $y_3 = [(x'_1)^2 + (y'_1)^2]^{1/2}$  and  $x'_1 = x_1$ ,  $y'_1 = y_1/e_1$ .

**At the seventh stage**, the target's rotation  $e_2$  is determined based on the value  $x_{30}(e_2)$  extraction.

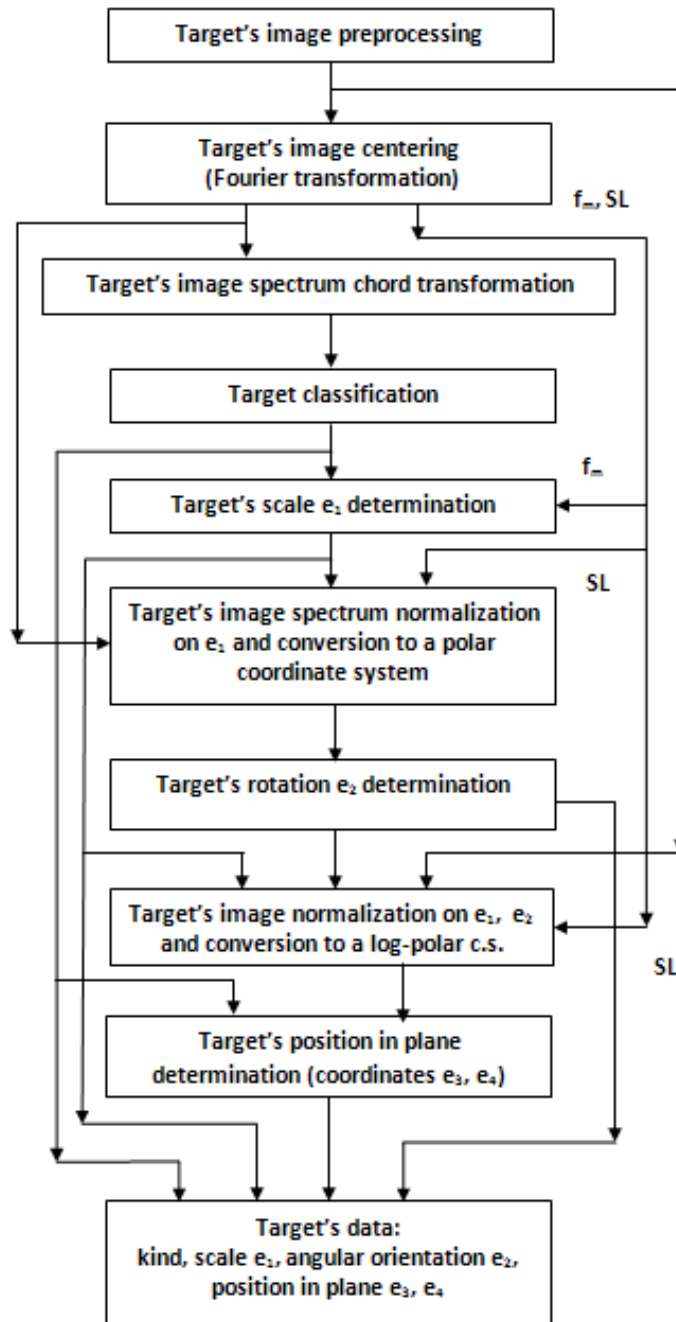
**At the eighth stage**, the target's image normalization on parameters  $e_1$  and  $e_2$  is made:

$$P(x',y') = P(x+e_3, y+e_4, e_1, e_2) \rightarrow P(x'_4, y'_4) = P(x_4+e_3, y_4+e_4), \quad (6.5)$$

were  $x'_4 = [x' \cos(-e_2) - y' \sin(-e_2)]/e_1$ ,  $y'_4 = [x' \sin(-e_2) + y' \cos(-e_2)]/e_1$ .

**In the ninth stage**, the target's parameters  $e_3, e_4$  will be determined via the correlation function calculation:

$$U(x_5, y_5) = \max\{\iint P(x'_4, y'_4) P_s(x_4, y_4) dx_4 dy_4\} \quad (6.6)$$



**Figure 4.** The method TRM4 of target recognition.

The main differences between method TRM4 and previous methods consist in the following. 1. The target is classified, after which there are determined all his parameters. 2. Target is classified and parameters  $e_1$  and  $e_2$  are determined based on the target's image Fourier spectrum.

## 7. Comparison of the target's recognition methods

The elaborated methods permit the classification of the targets and determination of their parameters – position in the plane, scale, and angular rotation. The comparative data regarding target's recognition methods TRM1÷TRM4 are presented in Table 1 and Figure 5.

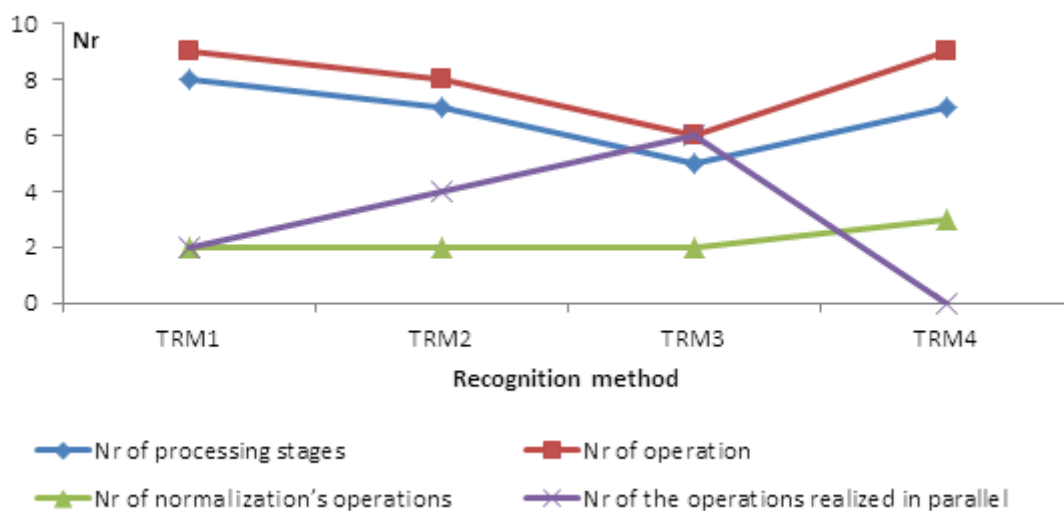
Table 1

Target's recognition methods comparative data					
	Recognition method	TRM1	TRM2	TRM3	TRM4
1.	Sequences of operations	PP-F-P-N-CT-C-S-N1-R	PP-F-P-N-CT-C-N2-S,R	PP-P,N3-CT1-C-N4-S,R	PP-N3-CT1-C-S-N5-R-N6-P
2.	Kind of method	Parameters – Classification-Parameters	Parameters – Classification-Parameters	Parameters    Classification-Parameters	Classification-Parameters
3.	Processing of the:	Target's image	Target's image	Target's image Fourier spectrum	Target's image Fourier spectrum
4.	Nr of processing stages	8	7	5	7
5.	Nr of operations	9	8	6	9
6.	Nr of image normalization's operations	2	2	2	3
7.	Nr of the operations realized in parallel	2- P, F	4: 2 - P, F; 2-S, R	6: 2 – P, F; 2 - N5, CT; and 2 - S, R	-
8.	Determination of the parameters S and R	Consecutive	Parallel	Parallel	Consecutive
9.	Target's rotation determination approach	Faze extraction	Correlation	Correlation	Faze extraction

The comparison of the elaborated target recognition methods shows the following.

1. Depending on the consequence of the operations of the target classification and his parameters determination, the methods can be divided into 2 groups - "Parameters – Classification - Parameters" (methods TRM1÷TRM3) and "Classification - Parameters" (method TRM4).
2. The methods TRM1 and TRM2 are based on the processing of the target's image, and methods TRM3 and TRM4 – on the processing of the target's image Fourier spectrum.
3. The methods TRM3 and TRM4 don't need the preliminary determination of the target's position in the plane to center the target's image.
4. Method TRM3 is characterized by minimal nr. of the processing stages (5 stages) and maximal nr. of operations realized in parallel (6 operations).
5. Utilization of the correlation approach at the target's scale and rotation calculation permits us to determine these parameters in parallel.

6. Method TRM1 needs the biggest nr of processing stages (8), and methods TRM1 and TRM4 need the biggest nr of processing operations (9)
7. Method TRM4 needs the biggest nr of the target's image normalization operations (3).
8. Methods TRM2 and TRM3 suppose the determination of the target's scale and rotation in parallel, using a correlation approach.
9. Methods TRM1 and TRM4 suppose the determination of the target's rotation based on the faze extraction approach.



**Figure 5.** Graphical presentation of the target's recognition methods comparative data.

### Conclusions

The new methods of the target recognition are described being based on the Central Image Chords Transformation.

Depending on the consequence of the operations of the targets classification and their parameters determination, the methods can be divided into 2 groups - "Parameters - Classification - Parameters" (methods TRM1÷TRM3) and "Classification - Parameters" (method TRM4).

The methods TRM1 and TRM2 are based on the processing of the target's images, and methods TRM3 and TRM4 – on the processing of the target's image Fourier spectrum.

Method M3 is characterized by minimal nr. of the processing stages and maximal nr. of operations realized in parallel. The methods TRM3 and TRM4 don't need the preliminary determination of the target's position in the plane to center the target's image.

Method TRM1 needs the biggest nr of processing stages. Method TRM4 needs the biggest nr of the processing operations and the target's image normalization operations.

Methods TRM2 and TRM3 suppose the determination of the target's scale and rotation using the correlation approach, which permits the determination of these parameters in parallel.

Methods TRM1 and TRM4 suppose the determination of the target's rotation based on the faze extraction approach.

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## ALGORITHM FOR SELF-TUNING THE PID CONTROLLER

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**Abstract.** An algorithm for self-tuning the PID controller to the second order systems is proposed in this paper. The proposed self-tuning procedure was developed according to the maximum stability degree criterion, the criterion that permits to achieve the high stability degree, good performance and robustness of the system. According to the proposed algorithm, the controller can be tuned according to the parameters that characterize the process and they can be determinate from the experimental response of the open loop system. To demonstrate the efficiency of proposed procedure of self-tuning the PID controller, the computer simulation was performed and the obtained results were compared with Haeri's method, maximum stability degree method with iterations and parametrical optimization method. According to the developed algorithm, it was performed the control of the thermal regime in the oven.

**Keywords:** *automatic control system, self-tuning algorithm, second order systems, performance of the control system, PID controller.*

**Rezumat.** Algoritmul de auto-acordare a regulatorului PID la sistemele de ordinul doi este propus în această lucrare. Algoritmul propus de auto-acordare a fost dezvoltat în baza criteriului gradului maximal de stabilitate, criteriul care oferă sistemului înalt grad de stabilitate, performanțe și robustețea ridicată. În conformitate cu algoritmul propus, regulatorul PID se acordează în dependență de parametrii care caracterizează procesul și care pot fi determinați din răspunsul indicial al sistemului deschis. Pentru a demonstra eficacitatea algoritmului propus a fost făcută simulare pe calculator și rezultatele obținute au fost comparate cu metoda Haeri, metoda gradului maximal de stabilitate cu iterații și optimizarea parametrică. Totodată, în conformitate cu algoritmul propus a fost proiectat algoritmul de reglare PID, în cazul sistemului de control a temperaturii în cuptor.

**Cuvinte cheie:** *sistem de reglare automat, algoritm de auto-acordare, sistemele de ordinul doi, performanțele sistemului automat, regulator PID.*

### Introduction

The PID control algorithm is the most used control algorithm applied to control the technological processes of heavy and light industries, due to its simplicity, easy implementation and maintenance [1, 2]. The practice of the automation demonstrates that

the PID controllers and its variation still remain poorly tuned in many industrial applications, due to inadequate choice of sampling period, nonlinear properties of control object or actuators, poor signal filtering, or wrong estimation of the mathematical model [3 - 5].

From these consideration for the last 40 years researchers have been focused on development the self-tuning algorithms, without the need the manual parameter tuning. The self-tuning algorithms significant improve the procedure of finding the tuning parameters of the controller, by the automatically adjustment the tuning parameters and maintaining the stability and robustness of the control system [6].

The most known algorithms, that are used for self-tuning are the methods such as Ziegler-Nichols and Cohen-Coon, due the fact that these methods don't require to be known the mathematical model of the control object. The Ziegler -Nichols method can be used for the case of closed-loop systems in online mode, that suppose the control object to be excited to generate the critical oscillation regime, and according to which can be obtained the parameters for calculation the tuning parameters. The advantage of this method is the easy implementation, but as disadvantage can be considered the ensuring of the low performance of the system [7].

The Cohen-Coon method is applied for the open loop systems, for the case then control object has the slowly time-varying behavior with a large dead time [1]. The Cohen-Coon tuning method is used in offline mode, that means that a step change can be applied to the input of the system and then the output is obtained, and based on it is calculated the time constant and the time delay, that are used for tuning the PID controller.

In response to these limitations, the relay auto-tuning methods were proposed by Åström and Hägglund [8], that are widely used due to applicability in slow or highly nonlinear systems and simple mechanism of identification and calibration. Other methods for self-tuning were proposed by Dormido and Morilla and Ho et al. [9 - 10] based on sensitivity and phase margin; by Liu and Daley and Tan et al. based on the performance criterion [11]. More recent developments methods integrate the relay characteristic methods with algorithms from artificial intelligence such as the neural networks, evolutionary algorithms and fuzzy control, that permit to reduce the effect of perturbation signal or nonlinear behavior of the control object. However, these approaches increase the complexity of the self-tuning algorithm [9 - 13].

In this work, it is presented the algorithm for self-tuning the PID controller to the second order systems with oscillate and aperiodic step response. The PID controller is proposed to be tuned based on the analytical expressions that were obtained according to the maximum stability degree (MSD) criterion [14, 15] and these expressions depend on the control object parameters, which can be obtained from the experimental curve of the open-loop system.

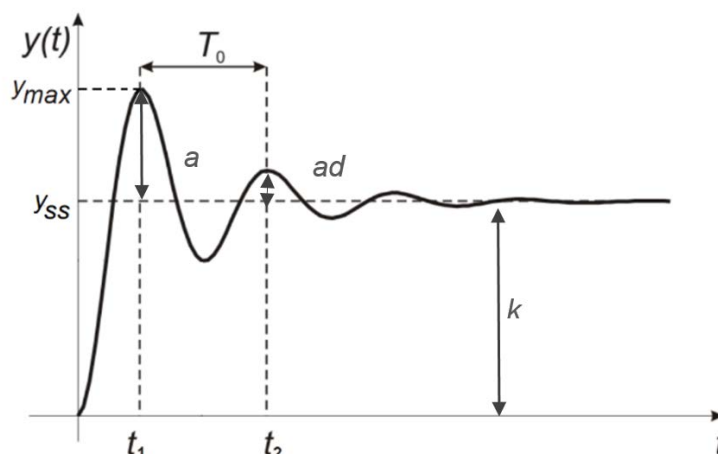
## 1. Self-Tuning PID Algorithm

### A. Identification procedure for control object with oscillate step response

It is assumed, that the oscillate step response of the open loop system is given, Figure 1. The transient response presented in the Figure 1, can be approximated with the following transfer function [1, 8]:

$$H_F(s) = \frac{k \omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} = \frac{k}{a_0 s^2 + a_1 s + a_2}, \quad (1)$$





**Figure 1.** Oscillate step response.

where  $\omega_n$  - natural frequency,  $\xi$  - damping ratio,  $k$  - transfer coefficient and  $a_0 = 1/\omega_n^2$ ,  $a_1 = \frac{2\xi}{\omega_n}$ ,  $a_2 = 1$ .

The value of the damping ratio can be calculated from the experimental curve according to the following expression [8]:

$$\xi = \frac{1}{\sqrt{1+(2\pi/\log d)^2}} \quad (2)$$

where  $d$  - is decay ratio.

The value of the natural frequency can be calculated by:

$$\omega_n = \frac{2\pi}{T_0\sqrt{1-\xi^2}} \quad (3)$$

where  $T_0 = t_2 - t_1$  is period of oscillation.

The value of the transfer coefficient can be calculated by the following relationship:

$$k_F = \lim_{t \rightarrow \infty} \frac{\Delta y}{\Delta u} = \lim_{t \rightarrow \infty} \frac{y_{st} - y_{initial}}{u - u_{initial}} \quad (4)$$

where  $u$  - is the value of the input signal.

In this way the classical identification method of the second order transfer function is based on locating the value of overshoot and peaks at  $t_1$  and  $t_2$  [8].

### B. Identification procedure for control object with aperiodic step response

It is assumed, that the aperiodic step response of the open loop system is given, Figure 2.

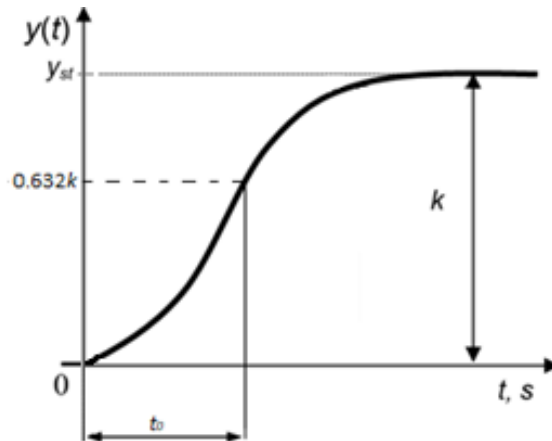
The transient response presented in the Figure 2 can be approximated with following transfer function [16]:

$$H_F(s) = \frac{k}{(T_1s+1)(T_2s+1)} = \frac{k}{a_0s^2 + a_1s + a_2} \quad (5)$$

where  $T_1, T_2$  - time constants,  $k$  - transfer coefficient and  $a_0 = T_1T_2$ ,  $a_1 = T_1 + T_2$ ,  $a_2 = 1$ .

It is used the following procedure for determination the parameters  $k, T_1, T_2$ :

1. From the experimental curve (Figure 2), it is calculated the value of the transfer coefficient by the (4) relationship. Next it is calculate the value of the  $y(t)$  at the level  $0,632k$ , according to this value it is calculated the value of  $t_0$  (Figure 2).



**Figure 2.** Aperiodic step response.

2. It is calculated the values of the time constants  $T_1$  and  $T_2$  for the model of object (5) [16 - 17]:

$$T_1/T_2=0.5,$$

$$T_2=0.64t_0, \quad (6)$$

$$T_1=0.5T_2=0.5 \cdot 0.64t_0=0.32t_0.$$

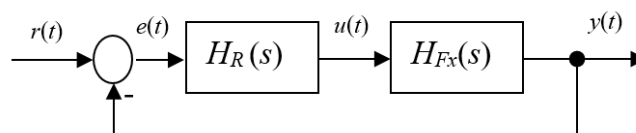
By the relations (6), there are calculated the coefficients  $a_0, a_1, a_2$ :

$$a_0=T_1T_2=0.32 \cdot 0.64T^2=0.2048T^2,$$

$$a_1=T_1+T_2=0.32T+0.64T=0.96T, \quad a_2=1. \quad (7)$$

### C. Algorithm for self - tuning the PID controller

In this study, the automatic control system it is described by the structural scheme presented in the Figure 3, that consists from the controller with transfer function  $H_R(s)$  and control object described by the (1) or (5) transfer functions.



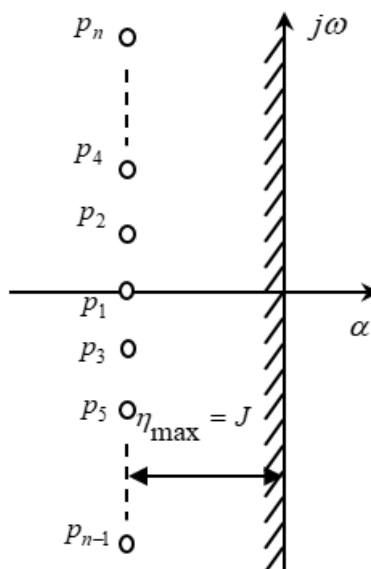
**Figure 3.** Structural scheme of the automatic control system.

The control algorithm PID is described by the following transfer function:

$$H_R(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k_i + k_p s + k_d s^2}{s}, \quad (8)$$

where the tuning parameters -  $k_p$ ,  $k_i$ ,  $k_d$  are the coefficients for the proportional, integral, and derivative components of the PID controller.

One of the criterion, that is used for tuning the PID controller is the maximum stability degree criterion [14, 15, 19]. This criterion ensures the maximum displacement of the dominant poles of closed loop system to the imaginary axe in the left complex half plane (Figure 4).



**Figure 4.** Placement of the poles in the left complex half plane for the system with MSD.

Based on the transfer functions in form (1) or (5) and transfer function of the PID controller (8), it was obtained the following characteristic equation of the closed loop control system

$$A(s) = \frac{1}{k}(a_0s^3 + a_1s^2 + a_2s) + k_d s^2 + k_p s + k_i. \tag{9}$$

According to the MSD criterion, the tuning parameters of the controller should be determinate, so as to be satisfied the condition [14 - 15]

$$J = \eta_m = \max \eta(k_p, k_i, k_d),$$

where  $J$  is the maximum stability degree;  $\eta$  - the stability degree of the system.

**Statement 1.** [18] If the coefficients  $a_0$  and  $a_1$  of the characteristic equation are set, than the stability degree  $\eta$  of the stable system achieve the maximum possible value equal with

$$J = \eta_m = \frac{a_1}{na_0}, \tag{10}$$

when the real parts of all poles are equal to each other  $\alpha_1 = \alpha_2 = \dots = \alpha_n = J$ .

In equation (10)  $n$  is the degree of the characteristic equation of closed-loop control

system. For the case when number of the tuning parameters is equal or less than the characteristic equation order, the value of the MSD can be chosen as arbitrary number [17]. Therefore, in this work, it was proposed that the MSD value to be calculated by the following expression:

$$J = \eta_m = \frac{a_1}{(n-1)a_0}. \quad (11)$$

In the paper [19], it was developed MSD method with iteration for tuning the PID controllers and according to this method by the experimental way it was observed that

$$J = \eta_m = \frac{k_d}{2k_p}. \quad (12)$$

In this case, by doing the equaling of the expressions (11) and (12), it is obtained

$$\frac{k_d}{2k_p} = \frac{a_1}{(n-1)a_0}. \quad (13)$$

Next, according to the MSD method [15,19], there are obtained the analytical expressions for calculation the tuning parameters to the model of object (1) or (5):

$$k_p = \frac{1}{k}(-3a_0J^2 + 2a_1J - a_2) + 2k_dJ, \quad (14)$$

$$k_i = \frac{1}{k}(a_0J^3 - a_1J^2 + a_2J) - k_dJ^2 + k_pJ, \quad (15)$$

$$k_d = \frac{1}{2k}(6a_0J - 2a_1). \quad (16)$$

In this way, for the case of aperiodic transient response of the system, using the (12)-(13) expressions, the functions (14)-(16) can be rewritten as:

$$k_p = \frac{a_1^2}{2ka_0} = \frac{(T_1 + T_2)^2}{2kT_1T_2}, \quad (17)$$

$$k_i = \frac{a_1}{2ka_0} = \frac{(T_1 + T_2)}{2kT_1T_2}, \quad (18)$$

$$k_d = \frac{a_1}{2k} = \frac{T_1 + T_2}{2k}. \quad (19)$$

For the case of oscillate transient response of the system, using the equations (2)-(3) the equations (17)-(19) can be rewritten as:

$$k_p = \frac{2\xi^2}{k}, \quad (20)$$

$$k_i = \frac{\xi\omega_n}{k}, \quad (21)$$

$$k_d = \frac{\xi}{k\omega_n}. \quad (22)$$

According to the expressions (17)-(19) and (20)-(22) the tuning parameters depend on the object parameters, that are known. In this way, the procedure of self-tuning can be implemented and requires the identification of the object parameters namely the damping ratio, transfer coefficient and natural frequency for the oscillate process, or time constants for aperiodic process, that can be determinate based on the experimental curve of the open loop system.

The algorithm for self-tuning the PID controller is following:

1. Obtaining the experimental curve of the open loop control system.
2. Identification the parameters of the model of object based on the experimental oscillate or aperiodic experimental curve, based on the expressions (2) and (3) and (4), or expressions (6)-(7).
3. Calculation the tuning parameters of the PID controller based on the expressions (17)-(19) for aperiodic process, or (20)-(22) for oscillate process.

## 2. Study Case and Computer Simulation

### A. Tuning the PID controller to the control object with oscillate step response

It is considered, that the control object is described by the transfer function with inertia second order

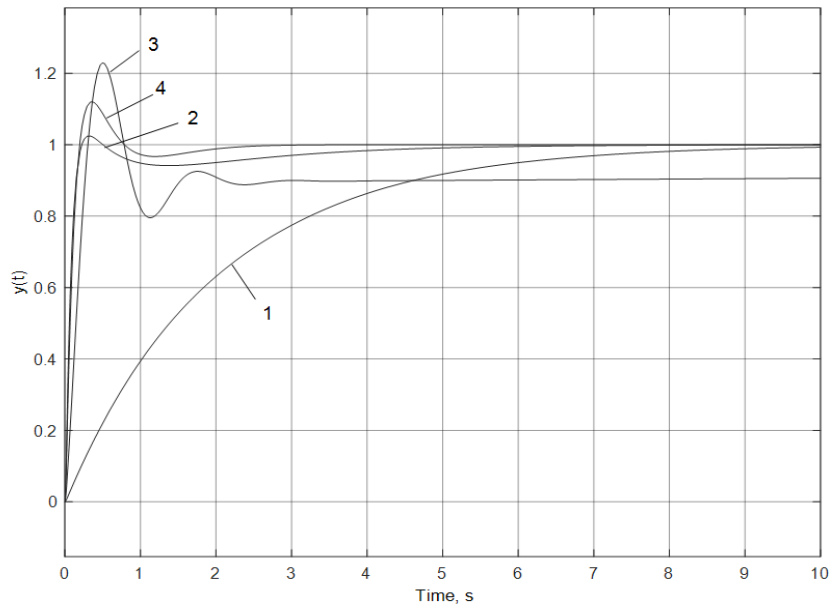
$$H_F(s) = \frac{k\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} = \frac{3}{s^2 + s + 3}, \quad (23)$$

where  $\omega_n=1.73$ ,  $\xi=0.288$ ,  $k=1$ .

Applying the expressions (20)-(22) there are obtained the values of the tuning parameters, that are presented in the Table 1 (row 1). The obtained results were compared with results obtained for the case of tuning the PID controller by the parametric optimization method (row 2), Haeri's method (row 3) [7], maximum stability degree method with iteration (row 4). The obtained simulation results are presented in the Figure 5, where the numbering of the curves correspond with the numbering of the methods from the Table 1.

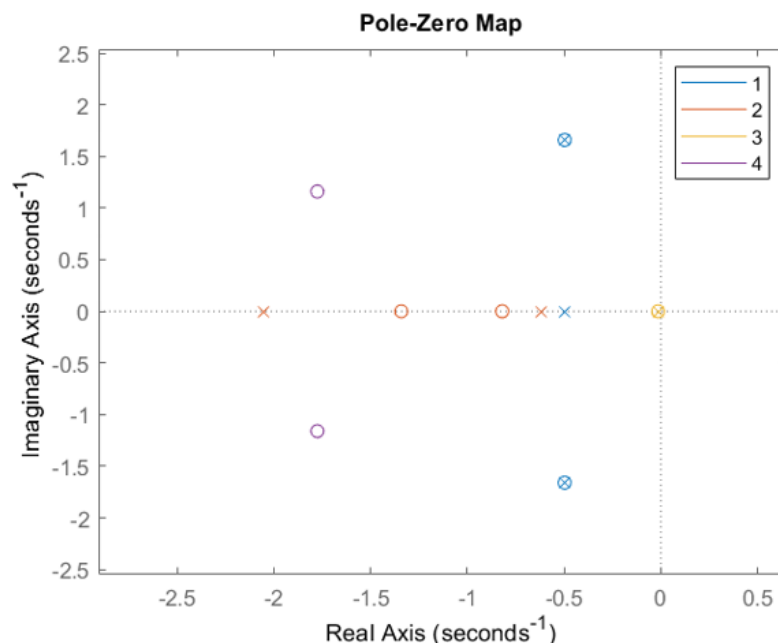
Table 1

Tuning parameters and automatic system performance							
No.	$k_p$	$k_i$	$k_d$	$t_s$	$t_r$	$\sigma, \%$	$\eta$
1	0.16	0.49	0.16	4.40	7.8	0	0.5
2	8.66	4.40	4.011	0.15	3.6	1.91	0.6
3	8.38	0.11	0.929	0.23	132.7	21.91	0.01
4	11.18	14.16	3.15	0.15	1.7	11.41	2.9



**Figure 5.** Transient response of the automatic control system.

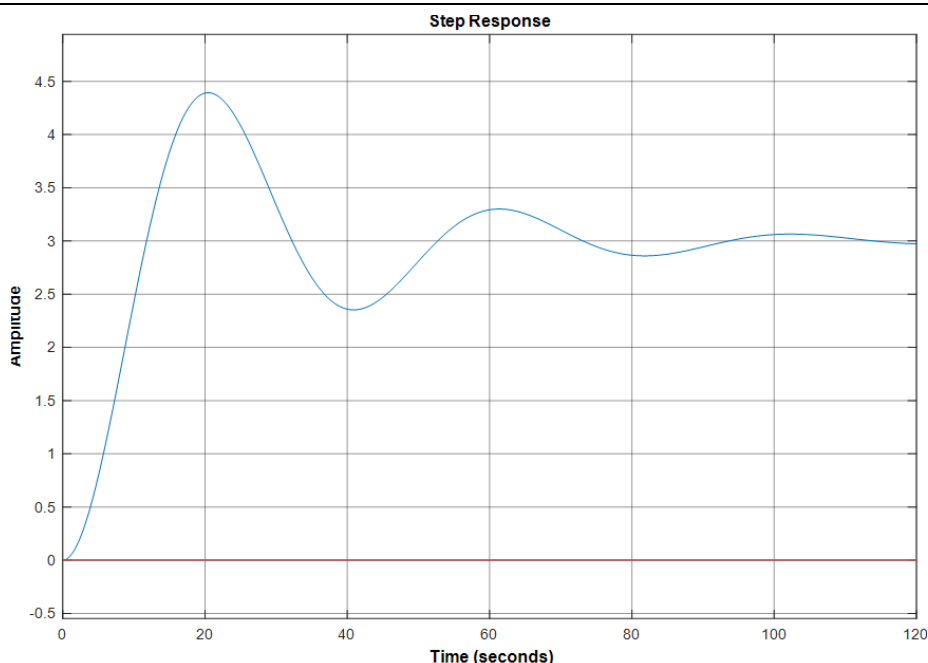
From Figure 5, it can be observed, that in case of using the proposed algorithm for tuning the controller it can be obtained the aperiodic transient response without overshoot, with high settling time. The MSD criterion offers to the system the high stability degree and it was done the analysis of the systems' stability degree. There is obtained the distribution of poles and zeros of the closed loop system in the complex plan (Figure 6), where the numbering corresponds with the numbering of the methods from the Table 1, and the obtained values of the stability degree for each method are presented in the Table 1.



**Figure 6.** Poles-zeros distribution.

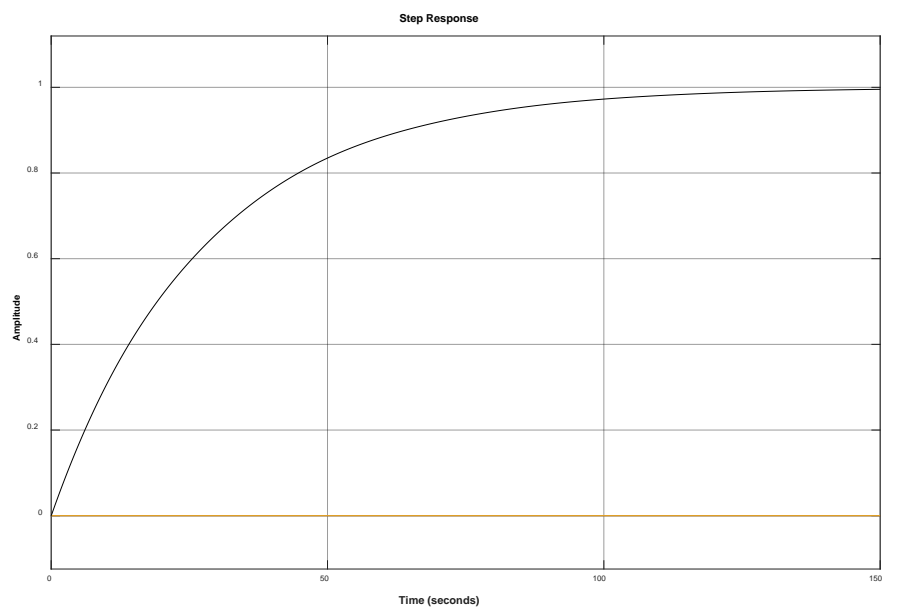
Next, it is presented an example of application the proposed algorithm of self-tuning the controller, it is supposed that control object is characterized by the oscillate transient response, Figure 7. According to the expressions (2)-(3) and (4) there are calculated  $\omega_n = 0.1616$ ,  $\xi = 0.236$ ,  $k=3$  and the transfer function that approximates the experimental curve

$$\text{is: } H_F(s) = \frac{k \omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} = \frac{0.0783}{s^2 + 0.0762s + 0.0261}.$$



**Figure 7.** Step response.

Based on the expressions (20)-(22) for calculation the tuning parameters, there are obtained  $k_p=0.037$ ,  $k_i=0.012$ ,  $k_d=0.488$  and the simulation result of control system is presented in the Figure 8.

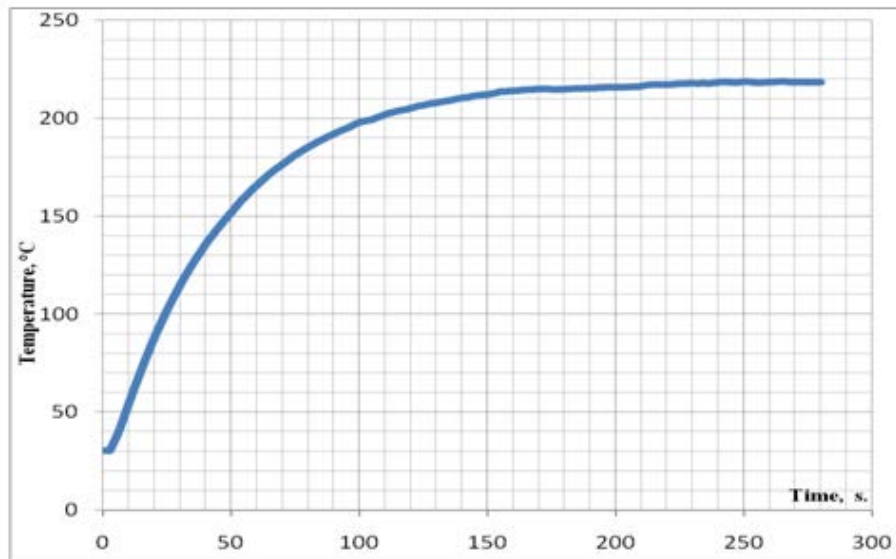


**Figure 8.** Transient response of the automatic control system.

#### *B. Tuning the PID controller to the control object with aperiodic step response*

It was proposed to control the thermal regime in the oven and to tune the PID controller according to the proposed algorithm. For the first step, it was necessary to determinate the mathematical model, that approximates the process of variation the temperature in the oven and it was raised the experimental curve (Figure 9).

Based on the described algorithm for approximation the aperiodic step response with transfer function (5), from the experimental curve (Figure 9) there are calculated that  $0,632k$  is equal with 137.77 and according to this value there is obtained that  $t_0=44.2696$ , when the calculations are



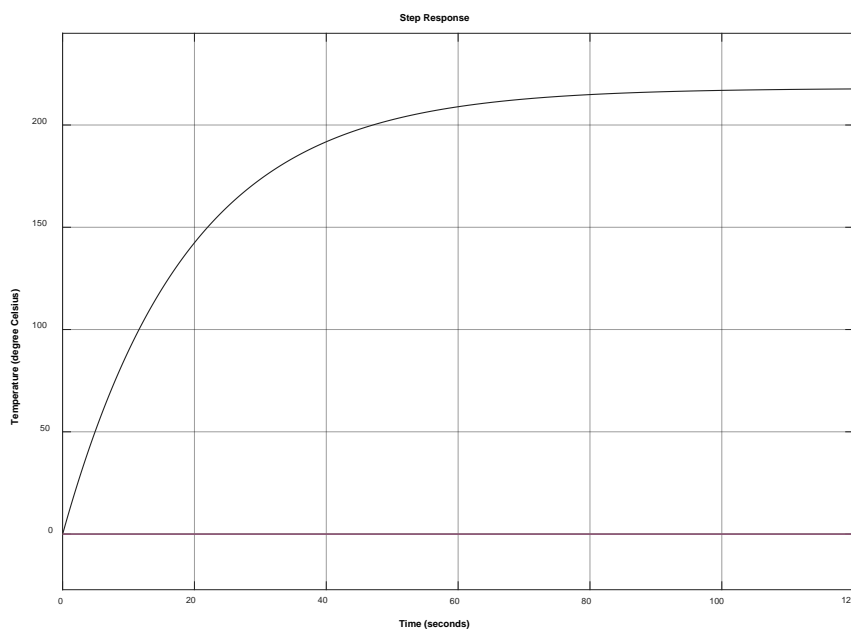
**Figure 9.** The experimental curve.

$$T_0 = 0.64 \cdot 44.2696 = 28.3325 \text{ s}; \quad T_1 = 0.5 \cdot 28.3325 = 14.1663 \text{ s}.$$

In this case the obtained transfer function is

$$H_F(s) = \frac{k}{(T_1s + 1)(T_2s + 1)} = \frac{1.0035}{(28.3325s + 1)(14.1663s + 2)} = \frac{1.0035}{401.3667s^2 + 42.4988s + 1} \quad (24)$$

Based on the expressions (17)-(19) for calculation the tuning parameters, there are obtained  $k_p = 2.2421$ ,  $k_i = 0.0528$ ,  $k_d = 21.175$  and the simulation results of control system with PID controller tuned by the proposed algorithm is presented in the Figure 10.



**Figure 10.** Transient response of the automatic control system.

## Conclusions

An algorithm for self-tuning the PID controller to the second order systems is proposed in this paper. The tuning parameters can be calculated according to the proposed analytical expressions that depend on the value of the damping ratio, transfer coefficient and natural frequency of the system, which can be obtained from the experimental curve of the open-



loop system. These expressions were developed according to the MSD criterion, the criterion that ensures the good performance and high stability degree to the system. To demonstrate the efficiency of the proposed algorithm it was done the computer simulation and the comparison with MSD method with iterations, the optimization method from MATLAB and Haeri's method. It was observed that the proposed self-tuning algorithm ensures to the system the aperiodic step response, but with high settling time.

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## CYBER SECURITY STRATEGIES FOR HIGHER EDUCATION INSTITUTIONS

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**Abstract.** Due to the large volume of data they manage, Higher Education Institutions (HEIs) are perfect targets for cyber attackers. University networks are open in design, decentralized and multi-user, making them vulnerable to cyber-attacks. The purpose of this research paper was to identify which is the recommended cyber security strategy and how comprehensive are these studies, within HEIs. The method proposed by Kitchenham was used, focused on the information community. Thus, the following results can be communicated: researchers recommend their own security strategies, because the standards analysed in the papers are not oriented on HEIs, and require important adjustments to be implemented. Most scientific papers do not describe risk management process. The implementation phases are also insufficiently analysed. The functions that the strategy addressed by HEIs should fulfill include identification, protection and detection. The validation methods used in the pre-implementation and post-implementation phases are case studies and surveys. Most researchers recommend as final cyber security strategy IT Governance and security policies. The field of research has proved to be very interesting, the researches could contribute to the creation of a comprehensive cybersecurity strategy, focused on the specifics of HEIs, efficient, easy to implement and cost-effective.

**Keywords:** *cyber security, strategy, risk management, HEI, framework, standard.*

**Rezumat.** Datorită volumului mare de date pe care le gestionează, instituțiile de învățământ superior (IIS) sunt ținte perfecte pentru atacatorii cibernetici. Rețelele universitare sunt deschise în design, descentralizate și multi-utilizator, deci vulnerabile la atacuri cibernetice. Scopul acestei lucrări de cercetare a fost să identifice care este strategia de securitate cibernetică recomandată și cât de cuprinzătoare sunt aceste studii, realizate în cadrul instituțiilor de învățământ superior. S-a folosit metoda propusă de Kitchenham, axată pe comunitatea informațională. Astfel, se pot comunica următoarele rezultate: cercetătorii recomandă propriile strategii de securitate, deoarece standardele analizate în lucrări nu sunt orientate spre IIS și necesită ajustări importante pentru a fi implementate; majoritatea lucrărilor științifice nu analizează procesul de management al riscului; fazele de implementare sunt insuficient analizate. Funcțiile pe care strategia abordată de IIS ar trebui să le îndeplinească includ identificarea, protecția și detectarea. Metodele de validare

utilizate în fazele de pre-implementare și post-implementare sunt studii de caz și anchete. Majoritatea cercetătorilor recomandă ca strategie finală de securitate cibernetică Guvernarea IT și politicile de securitate. Domeniul de cercetare s-a dovedit a fi foarte interesant, cercetările ar putea contribui la realizarea unei strategii cuprinzătoare de securitate cibernetică, axată pe specificul IIS, eficientă, ușor de implementat și rentabilă.

**Cuvinte cheie:** *securitate cibernetică, strategie, management al riscului, IIS, cadru, standard.*

### **Introduction**

With the development of information technologies, their use in HEIs has increased substantially. The year 2020 and the pandemic with Covid-19, made indispensable the use of new technologies to ensure the continuity of the university educational process, which passed in the online environment, requiring new technologies to be implemented. University networks had significant vulnerabilities even before the pandemic, as they are open in design [1], decentralized, multi-user and present data of maximum interest to attackers.

Universities are currently in the process of technological development. Access to technology is valuable in the development of modern learning environments, but on the other hand increases the vulnerability of communication networks and the number of threats. College campuses are some of the most technologically developed areas because it provides expanded support for Wi-Fi, online learning platforms (like Moodle), digital libraries, virtualization classes (teams, zoom, WebEx), web conferencing. All this, makes university networks very vulnerable due to large open networks, unlike other organizations [2].

Thus, in 2020 the education domain had a loss of \$ 3.90 million for data breach, according to IBM & Ponemon Institute [3], which conducts cybersecurity research. Referring to another study realized by CheckPoint [4], a leading provider of cyber security solutions to governments and corporations globally and in Europe too, the average number of weekly cyber-attacks per academic organization in July-August 2020, increased by 24%. In contrast, the overall increase in the number of attacks in all sectors in Europe was only 9% [5].

The implementation of an information security management system within HEIs is an important step in ensuring cyber security. With all the above, the studies in this field are very limited and do not contain implementation details, efficiency analysis and implementation of security frameworks in HEIs, rather, they have a superficial character, a theory supported by several international researchers [6–8]. The security framework is a comprehensive solution containing security policies, tools and procedures for strengthening cybersecurity and maintaining the information system [9–12].

A laborious study of the scientific literature in the field, it is necessary, to identify several key moments that will later allow to create a cyber security framework that is easy to implement, efficient and cost-effective. The main research question is: to identify the recommended security frameworks/strategies for HEIs, at international level, and how comprehensive are these studies, based on the review of the literature, published in the last 10 years. The research will focus on the analysis of the risk management and cyber security strategy, implementation phases, the functions of the security framework, validation methods and the finality of this process.

To achieve this goal, the search was performed in the following five scientific databases: Scopus, ScienceDirect, ACM Digital Library, IEEE Xplore and Springer. These databases have been selected because they are the most used for the study in the field of information security [12].

The article is organized as follows: in the first section we analyse the method proposed for literature review, we are planning and conducting the literature review, in the second section can be seen the report of literature review, based on the results found in section 1. Section 3 contains conclusions of the author and future research directions.

## 1. Research method

The method that was used to study the literature is based on the systematic review proposed by Kitchenham [13], aimed at the software engineering community. The systematic review of the literature is carried out in order to identify, interpret and evaluate research, relevant to a particular field. The individual studies conducted by researchers that contribute to the systematic review are primary studies and secondary studies, that result from the literature review. Thus, by the proposed method, the systematic review process involves the following 3 important phases: planning, conducting and reporting the review.

### 1.1. Planning the systematic review

The literature review planning process involves establishing a protocol. The review protocol includes the methods selected for the systematic review of the literature. The first step is to describe the background and establish the research questions, which follows.

There are several security frameworks used to implement the information security management system within organizations, such as ISO27001 [14], NIST [15], COBIT [16], ITIL [17]. However, according to several researchers, there is no framework that focuses specifically on cybersecurity in HEIs, as most security frameworks are aimed at commercial organizations [9 – 12], [18], or are difficult to implement and are not cost-effective.

So, the main research question (MRQ) is: "What is the cyber security strategy recommended within HEIs, how comprehensive are these researches?"

Complementary research questions (CRQ), to respond as accurately as possible to MRQ, are:

- CRQ1 - What is the security framework / standard recommended by researchers for HEIs? Do scientific papers include mechanisms for identifying security risks?
- CRQ2 - What are the phases of implementing the security framework in HEIs? What functions are considered relevant to the security framework?
- CRQ3 - What methods for evaluating the effectiveness of applied strategies.

At this stage, it is necessary to set the search terms and resources. Literature review was oriented on scientific articles and international conference proceedings, indexed in one of the following databases: Scopus, ScienceDirect, ACM Digital Library, IEEE Xplore, Springer.

The search was performed in the following metadata: the title, the keywords and the abstract of the scientific article but also in the content for more accurate results; based on the search terms set out in Table 1.

Table 1

Search terms	
No	Search terms
1	[Information Security] <b>or</b> [Information Security Management System] <b>or</b> [Cyber Security] <b>or</b> [IT governance] <b>and</b>
2	[Standard] <b>or</b> [Policies] <b>or</b> [Framework] <b>or</b> [Strategy] <b>and</b>
3	[Higher Education Institutions] <b>or</b> [HEI] <b>or</b> [Academia Institutes] <b>or</b> [University Campus] <b>or</b> [College]

The selection of primary studies is governed by inclusion and exclusion criteria [13]. The inclusion criteria of the scientific articles were:

- IC1: Studies that include research on security standards/frameworks;
- IC2: Studies that include the protocol for implementing the security standard/framework in HEI;
- IC3: Studies presenting categories, tools or policies relevant to the implementation of the security standard/framework in HEIs;
- IC4: Studies published since 2012 (to correspond to the objective of identifying the literature of the last 10 years).

The exclusion criteria from the research are:

- EC1: Only the abstract of the article is available;
- EC2: The study is not a research article or conference paper;
- EC3: The study contains the search terms in Table 1, because the authors work within HEIs and are not a study of information security in higher education institutions;
- EC4: Studies that reflect the importance of study programs (specializations) in the field of information security within the HEI.

## 1.2. Conducting the literature review

According to the search terms, 73 scientific papers were identified, however, a large part were excluded because they were not relevant according to the inclusion criteria set out in the previous step, or because they matched the exclusion criteria. So finally, were analysed 30 scientific articles, that were added in the Mendeley Reference Manager [19].

To perform a quality assessment, for each CRQ, has been set research criteria, reflected in table 2.

Table 2

Research criteria		
No.	Complementary research questions (CRQ)	Research criteria
1	What is the security framework/standard recommended by researchers for HEIs? Do scientific papers include mechanisms for identifying security risks?	Security framework or standard Risk Management framework
2	What are the phases of implementing the security framework in HEIs? What functions are considered relevant to the security framework?	Implementing phases Security framework functions
3	How is evaluated the effect of implementation of the security framework?	Operational architecture Validation methods

The relevance index [12] was calculated, according to the formula, each answer  $x_i$  can take the value 1, if the article solved all the research criteria and 0 otherwise:

$$Ri = \frac{\sum_{i=1}^n x_i}{n} * 100\% \quad (1)$$

where:  $n$  = number of selected items,  $i = \{1, \dots, n\}$

$x_i \in \{0, 1\}$

$Ri$  - can take values between 0 and 1, the value 1 takes if it meets all research criteria

It follows for each CRQ1, CRQ2, CRQ3, to extract, the research criteria, reflected in Table 2. Thus, the extracted data will be presented in the tables and graphically.

Using the method proposed by Kitchenham [13], based on formula (1), the relevance index ( $R_i$ ) of the scientific paper was calculated, the results can be seen in Table 3, sorted by relevance.

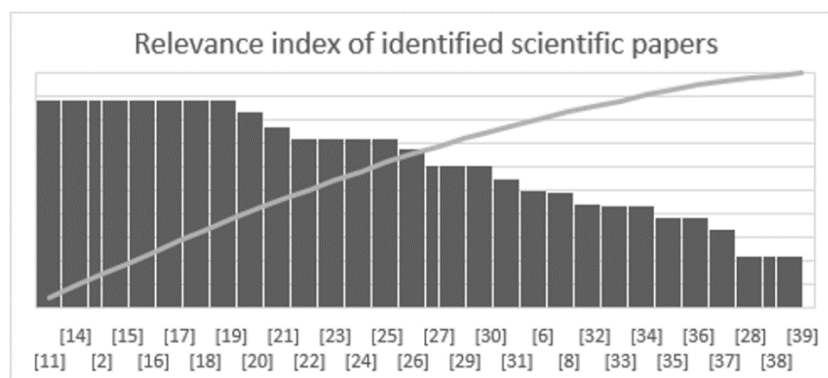
Table 3

<b>Selected scientific papers</b>			
<b>Reference</b>	<b>Scientific Paper</b>	<b>Publishing year</b>	<b><math>R_i</math></b>
[18]	Information Security Management in academic institutes of Pakistan	2013	0,89
[20]	An analysis of Indonesia's information security index: a case study in a public university	2018	0,89
[2]	Information security risks management framework – A step towards mitigating security risks in university network	2017	0,89
[21]	Developing an ISO27001 Information Security Management System for an Educational Institute: Hashemite University as a Case Study	2014	0,89
[22]	Information Security Risk Management in Higher Education Institutions: From Processes to Operationalization	2017	0,89
[23]	Today's Action is Better than Tomorrow's Cure - Evaluating Information Security at a Premier Indian Business School	2013	0,89
[24]	Emergence of Robust Information Security Management Structure around the world wide Higher Education Institutions: Institutions: a Multifaceted Security Solution	2012	0,89
[25]	IT Governance, Security Outsourcing, and Cybersecurity Breaches: Evidence from the U.S. Higher Education	2016	0,89
[26]	A study on integrating penetration testing into the information security framework for Malaysian higher education institutions	2015	0,83
[27]	Defense-through-Deception Network Security Model: Securing University Campus Network from DOS/DDOS Attack	2018	0,77
[16]	Cobit Framework as a Guideline of Effective it Governance in Higher Education: A Review	2013	0,72
[28]	Assessment of Information System Risk Management with Octave Allegro at Education Institution	2018	0,72
[29]	A generic framework for information security policy development	2017	0,72
[30]	Review of Information Security Policy based on Content Coverage and Online Presentation in Higher Education	2018	0,72
[31]	An Analysis of IT Assessment Security Maturity in Higher Education Institution	2016	0,68

Continuation Table 3

[32]	Information Security Management for Higher Education Institutions	2014	0,61
[33]	Information system and management for campus safety	2019	0,22
[34]	Towards an Unified Information Systems Reference Model for Higher Education Institutions	2017	0,61
[35]	Web vulnerability assessment and maturity model analysis on Indonesia higher education	2019	0,61
[36]	Implementing IT Security Penetration Testing in Higher Education Institute	2014	0,55
[6]	IT Governance Mechanisms in Higher Education	2016	0,50
[8]	Institutional governance and protection motivation: Theoretical insights into shaping employees' security compliance behaviour in higher education institutions in the developing world	2019	0,50
[37]	Missing Values Prediction for Cyber Vulnerability Analysis in Academic Institutions	2018	0,44
[38]	Implications, Risks and Challenges of Cloud Computing in Academic Field – A State-Of-Art	2019	0,44
[39]	Centralized IT Decision Making and Cybersecurity Breaches: Evidence from U.S. Higher Education Institutions	2020	0,44
[40]	Sixware Cybersecurity Framework Development to Protect Defence Critical Infrastructure and Military Information Systems	2021	0,39
[41]	The Design of Information Security Management System in College	2016	0,39
[42]	Analysis and Implementation of Operational Security Management on Computer Center At the University X	2014	0,33
[43]	An IT value management capability model for Portuguese universities: A Delphi study	2018	0,22
[44]	Cloud Computing: Empirical Studies in Higher Education A Literature Review	2017	0,22

Graphically, the results are shown in Figure 1.



**Figure 1.** Relevance of identified scientific papers.

The descriptive method will be used for data synthesis. The information extracted from scientific papers will be presented graphically using Venn diagram [45] and the circular diagram, which will generate graphics data to allow the visualization of the investigated data distribution. Graphs are a form of data abstraction and constitute an essential part of the data scientist's toolkit [45].

## 2. Reporting the literature review

### 2.1 Answer to complementary research question CRQ1

As reflected in Table 2, the research criteria that help to obtain a comprehensive response to CRQ1 are: recommended security framework/standard and risk management framework.

It is very important for HEIs to establish policies and control measures [32]. Security frameworks that assist to implement an Information Security Management Systems (ISMS) provide a complete solution for a better information security experience by providing the needed policies, tools and procedures for enhancing and maintaining a secured information system [21]. Another approach, but which supports the same idea, is that "The security framework is a complete solution that contains security policies, tools and procedures for strengthening cybersecurity and maintaining the information system" [9 – 12].

For a more efficient information security management system, it is mandatory to perform risk management, which refers to the confidentiality, integrity and availability of data related to the critical assets of HEIs [22]. Risk management can reduce the risks of certain important processes, financial losses or damage to reputation of HEIs [28], and support security policies creation [22].

These arguments served as a reason for analysing the recommended risk management strategies, along with the identification of ISMS recommended by researchers, as an integral part of the ISMS implementation process in HEIs, and increasing cyber security.

#### 2.1.1 Recommended framework/standard for security management

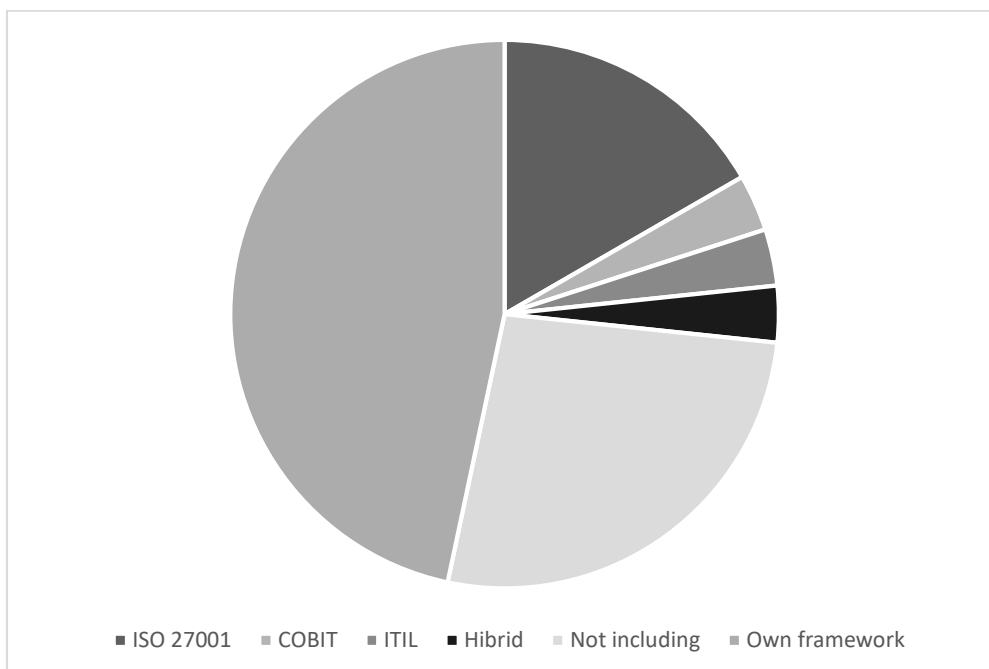
In order to answer at CRQ1, first criterion, it was necessary to identify, in the selected scientific papers, what are the recommended frameworks/standards. Table 4 reflects, the results of review, the recommended frameworks/standards are: ISO 27001, COBIT, ITIL, hybrid solution.

Many researchers provide own strategy, that confirms once again that the standards listed above are not oriented for implementation in HEIs, theory supported by several scientific studies.

Table 4

Criterion	Recommended security framework/standard		
	Framework	Scientific Paper	%
Recommended framework/standard for Information Security Management in HEIs	ISO 27001	5	16,67
	COBIT	1	3,33
	ITIL	1	3,33
	Hybrid	1	3,33
	Not including	8	26,67
	Own framework	14	46,67





**Figure 2.** Recommended framework/standard.

### ISO27001

ISO 27001 standard is the most widely used standard for information security at international level [18], [21]. In education, there has been a steady increase in the number of institutions certified to ISO 27001, so that in 2018 internationally certified were 137 institutions, in 2019, their number was 176 institutions certified [46], [47]. Most ISO 27001 certified institutions are in Japan (26), Greece (30), Italy (11), Poland (12), the Czech Republic (11).

The protection of corporate assets is achieved through the implementation of ISMS, which includes security risk assessment and is based on the CIA triad [14], [20], [47], [48].

The CIA triad refers to the three principles of information security [47]:

- Confidentiality, confirms that only authorized persons have access to information.
- Integrity, determines the accuracy with which data are processed.
- Availability, ensures that authorized persons access the data upon request.

As information security is not just about IT, the ISO 27001 standard also contains specific controls for human resource management, legal constraints and organizational management [47].

This is also due to the fact that cyber security depends more on the human factor than on the technology used [21], and the security threats coming from the employees of an organization are far superior to external threats [21].

The ISO 27001 standard is organized into 14 sections, 35 objectives and 114 security controls. For HEIs it is recommended to use at least 8 sections: asset management, human resources management, physical controls, access control, communications control, operational control, incident management, information system control and business continuity [32], [49]. Not all sections of the standard are applicable in HEIs, as the ISO 27001 standard is aimed at non-academic and commercial organizations [18].

Due to the general nature of the ISO 27001 standard, it is difficult to identify the targeted strategy specifically for HEIs, so empirical research could elucidate new variables that are not provided by the standards.

### *COBIT*

COBIT provides effective practices and establishes cybersecurity-specific activities in an organized and flexible structure. It enables the creation of IT control policies and promotes best practices at the organizational level [16]. COBIT focuses on generating a structured set of principles, such as organizational requirements, IT resources, IT processes and the provision of information [16]. The strategy proposed by COBIT is nothing more than a set of documents and good practices that support a specialist, auditor or user, to assess security risks, depending on the controls implemented and the technical problems faced by the organization [31].

COBIT is focused on risk management, as is ISO 27001, but it is a strategy that applies to IT Governance and is classified into 4 areas: Planning and Organization, Procurement and Implementation, Delivery and Support, Monitoring and Evaluation [50].

According to COBIT, control objectives refer to policies, procedures, practices and organizational structures that ensure the organization's objectives, as well as that any unexpected event is prevented or detected [16]. COBIT includes 34 IT processes and 13 control objectives. Each process contains a RACI diagram [16], which shows the role of each process in a managerial activity. The activities are identified from the control objectives and have a detailed structure.

As COBIT controls are mainly focused on achieving organizational objectives, it is further necessary for the security model to comply with the controls of the ISO 27001 standard, in order to ensure an optimal level of cyber security. Within the HEI, it is recommended to use COBIT to verify the maturity level of the model used [20] and to evaluate IT processes [16].

### *ITIL*

The ITIL standard is an association between different practices and information technology services for better management of IT services [31]. Services are characterized as a means of providing value to customers without increasing security risks or cost. ITIL is a library containing a set of 5 books and 26 processes that describe different phases of implementation and provide a systematic approach to IT Governance, operations management and control of IT services [17].

As in the case of COBIT, it is recommended to use the ITIL standard combined with the ISO 27001 standard, to integrate the security practices recommended by ISO 27001 in providing the best practical process management services recommended by ITIL. This will reduce the costs of maintaining an acceptable level of security, provide effective risk management and reduce security risks at all levels [31].

As outlined above, ISO27001 is the standard recommended by many researchers, even those recommended to implement their own strategies, does not deny the need for certification to ISO 27001, to have international value approved.

### **2.1.2 Recommended Risk Management framework**

With the increasing need for implementation and use of information technologies in HEI activity, risk management has become a mandatory process, integrated into the information security management system [42]. Risk management includes 3 processes [42]: Risk estimation, Risk mitigation and Assessment.

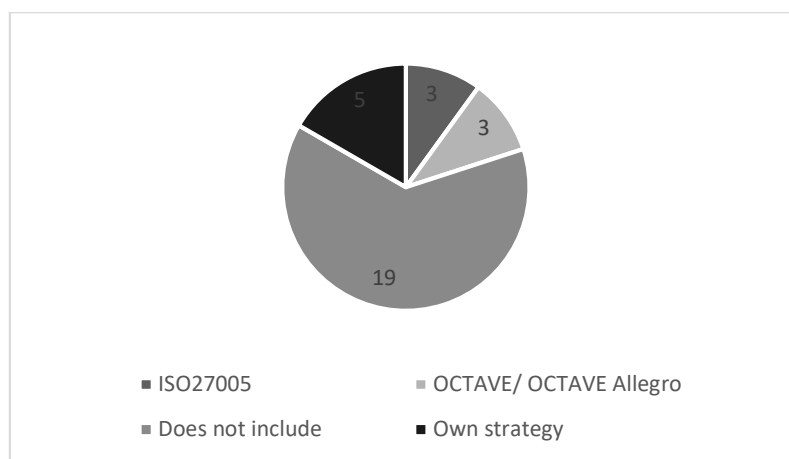
There are several models available for risk management, some are qualitative and others quantitative, the common goal being the value estimation of risk [2], [48]. The purpose

of applying a risk management model within the HEI is to quantitatively and qualitatively measure the level of risk for university assets [2].

The model selected must include security controls that are based on the real risks of the organization's assets and operations [2]. Following the study, it was identified that the main recommended models for risk management in HEIs are: ISO 27005, OCTAVE and OCTAVE Allegro, it can be seen in Table 5 and graphically in Figure 3. Also, in some scientific papers it is recommended to use strategies proposed by researchers, focused on the use of penetration tests to identify security risks [26], [35], [36]. However, although risk management is a mandatory process for ensuring cyber security in HEIs, much of the scientific work has not included a mechanism in this regard.

Table 5

Risk Management framework			
Criterion	Framework	Scientific Paper	%
Security framework/standard for Risk Management	ISO 27005	3	10,00
	OCTAVE/ OCTAVE Allegro	3	10,00
	Not including	19	63,33
	Own framework	5	16,67



**Figure 3.** Recommended Risk Management strategy.

### ISO 27005

ISO 27005 contains recommendations for risk management and is recommended by several researchers [18], [20], [21], [48]. The assets of the organization are classified into primary and support assets. The primary assets are all the processes and activities specific to the organization, and the assets: hardware, software, network, staff, website and organizational are support assets [48]. An important step for risk management, according to the ISO 27005 standard, is the classification of cyber security vulnerabilities according to the asset class to which they refer [21].

There are a number of vulnerabilities [21] that need to be analysed in the risk management process, which are further analysed:

- hardware components may be affected by moisture, dust, dirt and unprotected storage;
- software components can be easily exploited by unauthorized persons because they were not sufficiently tested before being exploited. Internal / external testing of software products could minimize cyber security risk [26], [36], [42], [51];

- security of communication networks [52–55], unprotected transmission lines or network architectures that do not involve the use of specialized security devices;
- personnel represent the most abstract category of vulnerabilities, attacks based on human behaviour represent 90% of all cyber-attacks [46];
- access to information assets, the risk that university sites will not be accessible due to flooding attacks is quite high, and the lack of power that can cause disconnection of servers on which web pages are hosted, is quite ubiquitous [35].

### *OCTAVE*

The OCTAVE model is very often used for risk management and is implemented in university security models to reduce the risk of cyber threats, by identifying the causes that make the university system vulnerable [2]. This is done by identifying university assets and assessing asset-specific vulnerabilities and threats [23]. OCTAVE contains specific activities, carried out in 3 phases [2], [23] and the practical approach that can be easily used in the university environment. The first phase consists in identifying the weaknesses in the system, dynamically (each new technology added to be subjected to risk analysis). The second phase focuses on high-risk areas, which are based on the risk score, for which the Common Vulnerability Scoring System (CVSS) is used [56], to validate the vulnerability that can be exploited.

The final phase involves the creation of a security risk remediation plan to monitor recursive risk assessment activities [2].

The main steps in implementing the OCTAVE model are: identifying assets, understanding security requirements, estimating vulnerabilities, analysing the effectiveness of security controls, assessing risk through the frequency and impact of cyber threats, designing remediation plans and making decisions based on comprehensive security reports [2].

The OCTAVE model was recommended by [2], [23] for implementation in HEI, as it allows to create a well-defined structure of security issues associated with the academic environment. It is cost effective, because it focuses only on real assets that are at risk.

### *OCTAVE Allegro*

OCTAVE Allegro has been recommended by researchers because it allows a more comprehensive assessment of the operational risk environment, in order to produce better results, without the need for extensive knowledge of risk assessment security [28]. This approach differs from the OCTAVE approach [28], focusing mainly on information assets in the context of how they are used, stored, processed and transferred, as well as extended to threats, vulnerabilities and any disruption [22].

The OCTAVE Allegro method is implemented in four stages:

- Setting up drivers
- Asset profile
- Identifying threats
- Risk identification and analysis

The advantages of this model are indisputable, because the score associated with the information risk is calculated based on the quantitative assessment of the threat, for example, if for a HEI the loss of reputation is important, then it will be assigned a higher score and risk mitigation measures, they will focus on information assets that contain more important data.

## 2.2 Answer to complementary research question CRQ2

CRQ2 is based on 2 research criteria: implementing phases and security framework functions. Having a relevant security framework for HEIs, it is necessary to know the phases of its implementation, because this is a very important process.

A security framework can be perfect but if it is implemented incorrectly, instead of benefits it could cause severe damage to organizations. So, the first criterion of CRQ2, allows to answer the scientific question which phases of the implementation of the security framework are recommended by researchers.

To create a security framework that will really enhance cybersecurity in HEIs, it is also necessary to analyse what functions it will have to perform. In this regard, the second criterion of CRQ2 has been defined, which will allow, after reviewing the selected scientific articles, to identify the functions considered relevant by researchers for an effective security framework.

### 2.2.1 Recommended implementing phases

Following the study, the common phases recommended for the implementation of the security model within the HEI can be identified.

According to the classification of the implementation phases in public organizations, made by Szczepaniuk E and others [57], there are 6 phases of implementation of security models in public organizations: defining security policies, defining the purpose, security risk assessment, risk management, selection of controls and the declaration of applicability.

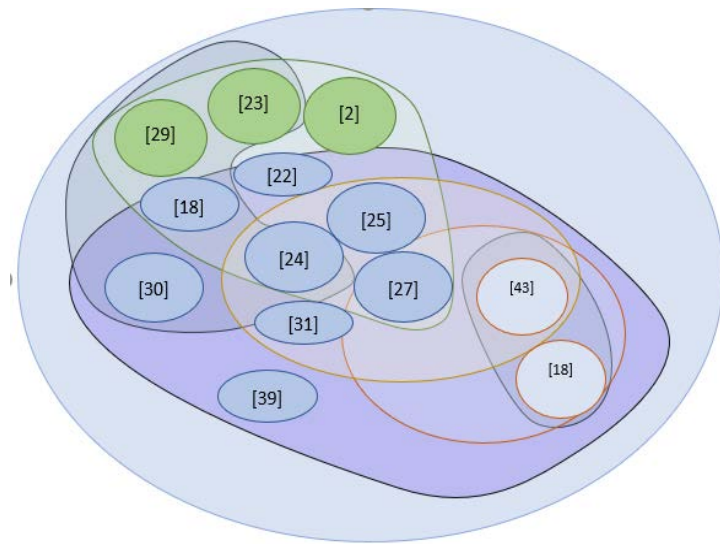
These phases were taken into account in order to be able to respond to first research criterion of CRQ2. The purpose was to identify the implementation phases on which the scientific papers focused, the phases are non-exclusive (an article may include 1 or more phases).

Thus, 7 scientific papers focused on defining security policies, 4 papers on defining the purpose, 8 papers on security risk assessment, 8 papers on risk management, 9 papers on the selection of security controls and 8 papers on the declaration of applicability, on analysis of conformity for selected controls.

Using Venn's diagram (Figure 4), the analysis of scientific papers that recommended one or more phases of the implementation of security models in HEIs was performed.

Table 6

Security framework implementation phases			
Phases of implementation of security models in HEIs	Scientific papers	No	%
Defining security policies	[18], [22], [24], [25], [30], [27], [31]	7	17,95
Defining the purpose	[21],[22],[24], [25]	4	10,26
Security risk assessment	[18],[2], [22], [23], [25], [29], [30], [31]	8	20,51
Risk management	[22], [2], [24], [29], [30], [27], [23], [39]	8	20,51
Selection of controls	[18], [21], [2], [32], [24], [33], [25], [30], [43]	9	23,08
Declaration of applicability	[18], [21], [2], [32], [22], [25], [27], [31]	8	20,51



**Figure 4.** Implementation phases.

According to the relevance index calculated in section 2, the phases of implementing the security model within the HEI were found in 14 scientific articles, of which 3 papers contained 4 phases according to the classification [57], 7 papers focused on 3 phases, 6 papers they focused on 2 phases and 2 scientific papers described only one phase. However, no paper includes all the recommended phases [57].

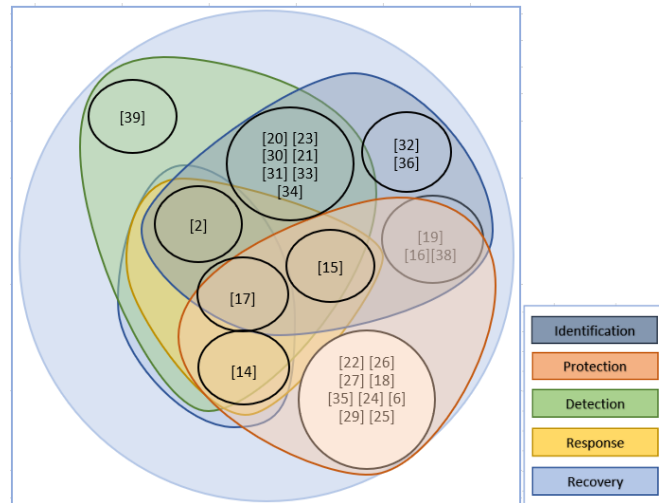
### 2.2.2 Recommended security framework functions

To answer the second criterion of CRQ2, it is necessary to identify which are the relevant functions of a security framework in HEI, recommended by international researchers. NIST standard defines 5 functions of the security framework: identification, protection, detection, response and recovery [51].

The analysed scientific papers recommend one or several functions simultaneously. Thus, out of the 30 papers analysed, 14 are focused on identifying security risks, 15 papers on asset protection, 11 scientific papers focus on detecting threats and vulnerabilities in the university information system, 4 papers are focused on making plans to respond to incidents of security and 3 works on the implementation of incident response plans aimed at mitigating security incidents. In this sense, the Venn diagram (Figure 5) was used, which graphically reflects the common or unique recommendations, in order to identify the functions considered important for the security framework.

*Table 7*

Security framework functions			
Relevant functions of the security framework for HEIs	Scientific Paper	No	%
Identification	[19], [20], [2], [15], [16], [23], [30], [17], [21], [31], [33], [34], [36], [38]	14	29,17
Protection	[22], [26], [17], [27], [18], [38], [35], [24], [6], [29], [25], [19], [14], [15], [16]	15	31,25
Detection	[20], [31], [33], [21], [39], [34], [14], [2], [17], [23], [30]	11	22,92
Response	[14], [2], [15], [17]	4	8,33
Recovery	[14], [2], [17]	3	6,25



**Figure 5.** Relevant ISMS functions for HEIs.

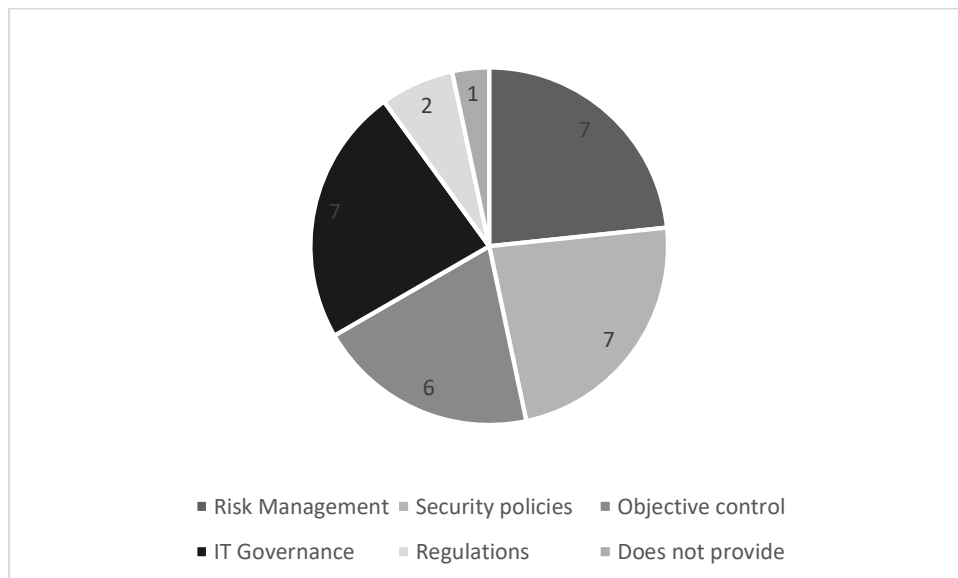
Thus, it can be concluded that researchers recommend for the realization of the security framework, applicable in HEI, the functions of identification (29,17%), protection (31,25%) and detection (22,92%). The response (8,33%) and recovery (6,25%) functions are insufficiently researched.

**2.3 Answer to complementary research question CRQ3**

To evaluate the effect of implementation of the security framework, it was set 2 research criteria: the operational architecture on which they are based (criterion 1 of CRQ3), the validation methods (criterion 2 of CRQ3), by which the effectiveness of the security framework is tested.

**2.3.1 Recommended operational architecture**

The analysis and evaluation of the implemented security strategies is based on: risk assessment, control of the completeness of the proposed security objectives, security policies, IT Governance and regulations. Thus, were obtained the data reflected in Figure 6. In the case of university networks, some researchers recommend that security policies be the final strategy for ensuring cyber security [29], [30], [42]. The purpose of security policies is to issue recommendations to end users on what assets they can use [42].



**Figure 6.** Evaluation of procedures.

A well-structured security policy should support top management to manage information risks and ensure the implementation of appropriate security controls [29]. According to research, some HEIs develop a single document containing all security policies and procedures, while other institutions develop different documents based on the requirements of ISO 27001, which is considered a best practice because it allows addressing to specific groups [30].

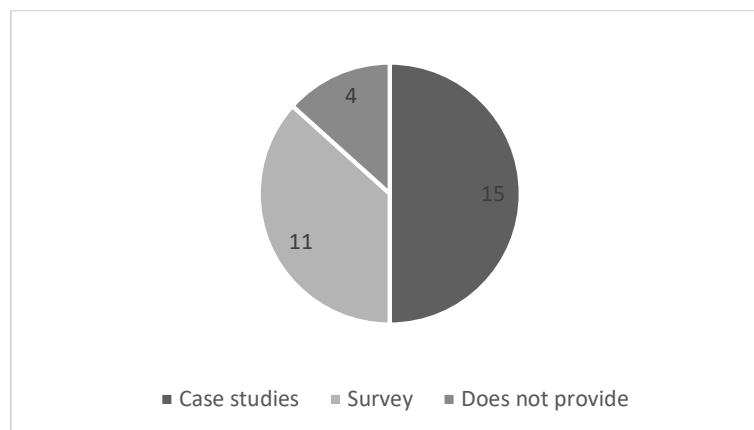
Several researchers [6], [16], [17], [39], [58] believe that efficient management of the IT infrastructure of the HEI is possible through the implementation of IT governance (ITG). ITG can be defined as a set of relational structures, processes and mechanisms that support the organization's management for the good management of the IT resources it manages. Thus, ITG can be analysed as a guide for the implementation of the cyber security control system [16]. Universities are complex organizations that require appropriate information systems to carry out their mission [6]. University information systems consist of different: applications, platforms, academic systems, cloud applications; which make the system heterogeneous [59]. All the above are necessary in the process of teaching, learning and conducting research activities, supported by university management.

Namely to manage with the efficient use of heterogeneous university IT resources it is necessary to implement ITG [6]. ITG relational mechanisms include participation and interaction between IT and administration [7], [16], but also educating employees and students to match the institution's expectations with user behaviour. Also, the creation of platforms for the distribution of successful practices for the implementation of ITGs within institutions, such as those in the UK (UCISA) or the USA (EDUCAUSE) and the certification of specialists in this regard, have increased the efficiency of ITGs in HEIs [7], [17], [58].

With all the above, studies in this field are very limited and do not contain implementation details, are relatively new and there are no relevant studies that would analyse the effectiveness and implementation of ITG in HEI, but are rather superficial, theory supported by several international researchers [6], [7], [60].

### 2.3.2 Recommended validation methods

The validation methods used by researchers to present the efficiency of their proposed framework, in the pre-implementation and post-implementation phases, are: case studies (15 scientific articles) that include the analysis of security systems and the use of penetration tests, surveys (11 scientific articles) that include the interview and the Delphi method [61].



**Figure 7.** Validation methods.



## Conclusions

This literature review was initiated to answer the main research question: "What is the cyber security strategy recommended within HEIs, how comprehensive are these researches?", in order to be able to build a security framework as comprehensive, efficient and cost-effective to increase cyber security under HEIs in the Republic of Moldova. It was very important to identify which security frameworks are recommended and analysed for implementation in HEIs, by researchers worldwide.

The 10-year period was chosen to analyse only scientific papers that are not outdated, because the IT sector is a very dynamic one. At the same time, this period allowed to analyse a larger number of scientific papers, which are still quite limited, few researchers focus on cybersecurity processes in HEIs, this statement is supported by several researchers, as specified in the introduction to this article.

Complementary questions helped to analyse these studies extensively, so the literature review did not focus only on metadata, such as: keywords, abstract or article title; but also on its content, because it was noticed that certain specifications found in the abstract of the article do not develop later in the content, from the perspective suggested at the beginning.

The method proposed by Kitchenham was applied, because it is "a guide for systematic analysis suitable for software engineering researchers" [13], a field related to cyber security. With this IT-oriented guide, it was easier to apply it, requiring only small adjustments along the way.

So, it possible now to answer the research question: "What is the cyber security strategy recommended within HEIs, how comprehensive are these researches?", by the following statements, that include also the answers to complementary questions, for a more comprehensive analysis and results:

- Researchers recommend the creation of a cyber security framework that supports ISO 27001 certification, in order to have international value. At the same time, it is necessary to identify the security framework that contains technical controls, focused on university assets, because the ISO 27001 standard specifies the objectives that the organization should achieve, but does not define how to do it.
- Risk management is identified as a key activity to implement an effective cyber security strategy. By estimating the impact that security risks may have, risk management plans will be identified to increase cyber security in HEIs. In this regard, scientific papers that included risk management strategies recommended the use of the ISO 27005 standard.
- The implementation phases of the security frameworks were described only in 14 out of 30 selected articles, but no article contains all the recommended phases for the implementation of ISMS in public organizations [57].
- The researchers consider relevant the following functions that the HEIs-oriented security framework should perform: Identification (29.17%), Protection (31.25%), Detection (22.92%).
- The finality is to build a cyber security framework that will support IT Governance and security policies creation.
- The validation methods used are: case studies, network penetration tests and surveys. This process makes it possible to identify the strengths and weaknesses of a security framework. It is a very important step in evaluating a cyber security framework.

The laborious review of the literature in this scientific paper is the knowledge base needed to create a cyber security framework, with the aim of increasing security in university networks. Thus, it was possible to identify the current state of scientific research in this field.

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## ASSURING THE SDN SECURITY BY MODELLING AND COMPARING SDN PROPOSED TOPOLOGIES USING PETRI NETS

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**Abstract.** The soaring number of applications for autonomous systems in different aspects like air, sea, and space is creating the need for new methodologies and architectures' technologies to consolidate the verification of system-level and system-of-systems level. The implementation of cybersecurity standards and software is critical to supporting infrastructure. This article discusses some security issues regarding autonomous systems' computer networks. It proposes the usage of Software-Defined Networks (SDN) technologies as a solution, after providing better security in SDN environment through the usage of the HYDRA framework and the usage of multiple controllers in specific topologies to ensure the security of SDN in precise and to ensure the security of the autonomous systems' computer networks in general as well. We propose a framework that contains 3 different types of controllers' topologies and each topology can use 4 algorithms, HYDRA, VPN, Double RSA, and least but not last comes blockchain technology which is the core of our security.

**Keywords:** *autonomous, systems, computer, network, security, SDN, technology, controller, topology, algorithm.*

**Rezumat.** Numărul tot mai mare de aplicații pentru sisteme autonome în diferite aspecte precum aerul, marea și spațiul creează nevoia de noi metodologii și tehnologii de arhitectură pentru a consolida verificarea la nivel de sistem și la nivel de sistem de sisteme. Implementarea standardelor și a software-ului de securitate cibernetică este esențială pentru sprijinirea infrastructurii. Acest articol discută unele probleme de securitate privind rețelele de calculatoare ale sistemelor autonome. Acesta propune utilizarea tehnologiilor Software-Defined Networks (SDN) ca soluție, după ce a asigurat o mai bună securitate în mediul SDN prin utilizarea cadrului HYDRA și utilizarea mai multor controlere în topologii specifice pentru a asigura securitatea SDN în mod precis și pentru asigurarea securității rețelelor de calculatoare ale sistemelor autonome și în general. Propunem un cadru care conține 3 tipuri diferite de topologii de controlere și fiecare topologie poate folosi 4 algoritmi, HYDRA, VPN, Double RSA, și cel mai puțin, dar nu ultimul, este tehnologia blockchain care este nucleul securității noastre.

**Cuvinte cheie:** *autonom, sisteme, computer, rețea, securitate, SDN, tehnologie, controler, topologie, algoritm.*

## 1. Introduction

The soaring number of applications for autonomous systems in different aspects like air, sea, and space is creating the need for new methodologies and architectures' technologies to consolidate the verification of system-level and system-of-systems level. The implementation is critical for backing up the cybersecurity standards and software infrastructure. The classical structure of networks has remained unchanged for a long time till the development of the new structure of software-defined network came up starting with its first attempt by Martin Casado which and that model was named Ethane [1]. Most security issues related to the heritage structure and hierarchy could be solved using the new paradigm of SDN but, due to the relative novelty of SDN methodology in managing the computer networks; many other new cyber-security challenges could emerge and with that comes the need to secure that environment to facilitate the transition from the classical network structure to the SDN structure and also there's a need to use risk assessment tools; both software and mathematical ones to determine the level of security risk that lies within a software-defined network environment since that it is useless or with less precision to use the common existing mathematical equations that were originally developed for assessing the security level in classical computer networks' environment.

There are many works and researches to use petri nets to study and analyze the security of computer networks in general like [2]; where they leveraged petri nets to model three defense scenarios the first one was with firewall only, the second was with firewall and Intrusion Detection System IDS and the third defense scenario was with firewall, IDS and a honeypot system. Also, many attempts to address the security issues in SDN in precise have been conducted including modeling the problems mathematically and graphically; the usage of petri nets was one of the main prominent methodologies used for that purpose [3] where they try in this work to model the SDN structure and model it under Denial of Service (DoS) attack but, not on the proposed topologies by this article. Also, in [4] the researchers tried to verify and give a general analysis for the security situation in the software-defined network environment that contains two switches and one controller; without the need to discuss the impact of a (DoS/DDoS) attack and again the modeled topology differs from those proposed in this article.

This article mainly discusses the topic of enhancing and ensuring the security of software-defined networks by suggesting several algorithms working together as a framework and by suggesting three different SDN controllers' topologies for the controllers of software-defined networks to overcome some cyber-security issues and to ensure the network reliability against various cyber-threats specifically, the threats of DoS/ DDoS [5]. We have discussed comparison. Also, this article presents a defense factor equation which is a new equation to assess the level of security risk in any SDN environment especially if it was based on any of the three presented structures in this research; since that most works haven't discuss that matter and even when they did, it wasn't based on the topologies proposed here and not discussing the previously mentioned attacks in precise as well and from that stems the importance and novelty of the research and this article that discusses it. And to discuss that specific matter, this article proposes the usage of petri nets modeling paradigm [9] to get simulation results to gain a better reading for the situation of the interaction between controllers and their networks and how would they react under the effect of DoS/DDoS attacks. In the section 2; we'll demonstrate briefly some of the main algorithms and methods proposed to form the framework that will be as a security solution each of them separately in

other articles [6 - 8] but here we'll gather them all for the purposes of to patch different security breaches, in section 3 we'll talk about the main idea of the paper which is the Petri Nets modelling for the suggested SDN controllers' topologies to derive an equation that could be used as a mathematical tool to measure the defense capabilities of the software-defined networks that leverage our proposed models against different cyber-threats; especially the DoS/DDoS attacks. Least but not last there will be a conclusion for the whole paper in section 4.

## 2. Integrated algorithms into the proposed framework

There are few algorithms proposed in the research and we'll describe them briefly here in this paper. Those algorithms work together to form the whole framework that will be installed on top of the management layer or the application plane which.

### Algorithms' suite integrated in HYDRA framework.

The framework will be installed upon the management plane; it is based on some algorithms and methodologies like the counter measurement attack against the perpetrator. Also it contains other technologies and algorithms as mentioned below.

### Secured channel of VPN algorithm.

The secured channel provided by Virtual Private Network (VPN) technology has a great deal of security that it provides; its Internet Protocol Security (IPsec) algorithm can be leveraged to ensure the security in the communication channel between SDN controllers that is called the east-westbound API [10].

### Cryptography of Double RSA algorithm.

The Rivest-Shamir-Adelman (RSA) algorithm is well known for its robustness in securing computer networks' communication till this day. This algorithm or methodology mainly consists of four stages, which are key generation, key distribution, encryption and decryption. The RSA algorithm contains two main keys' categories they are the public key and the private key. The stages of key generation are [11]:

1. The generation of two large prime numbers let us name them  $p$  and  $q$ .
2. The computation of  $n = p * q$ .
3. The computation of  $z = (p - 1) * (q - 1)$ .
4. Computation of the mod  $z = v$ .
5. Selecting a prime number to  $z$  and let's name it as  $x$ .
6. Figure out the value of  $e$ . then we put:  $e * x = 1 \text{ mod } z$  that means that:  $e * x = 1 * v$ .
7. Now let public key be  $(n, e)$
8. Now let private key be  $(n, x)$ .

It is proposed by this research to use it but in a full duplex-like way as shown in Figure 1.

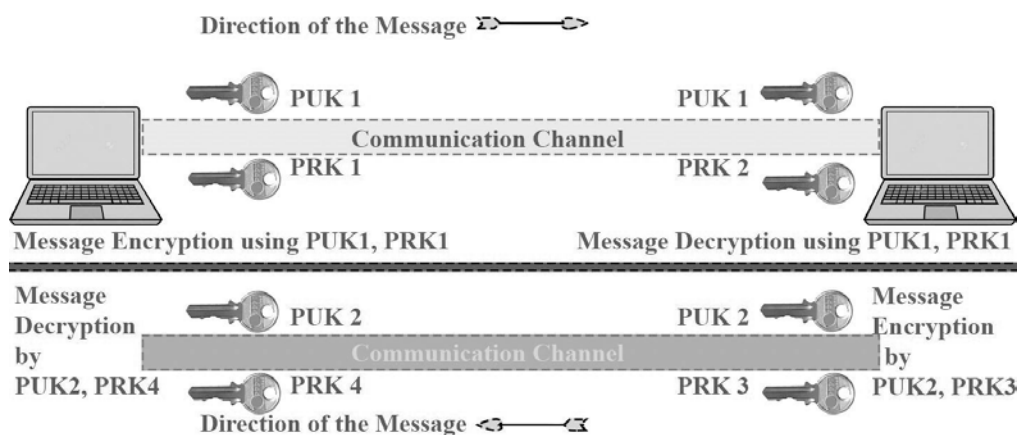


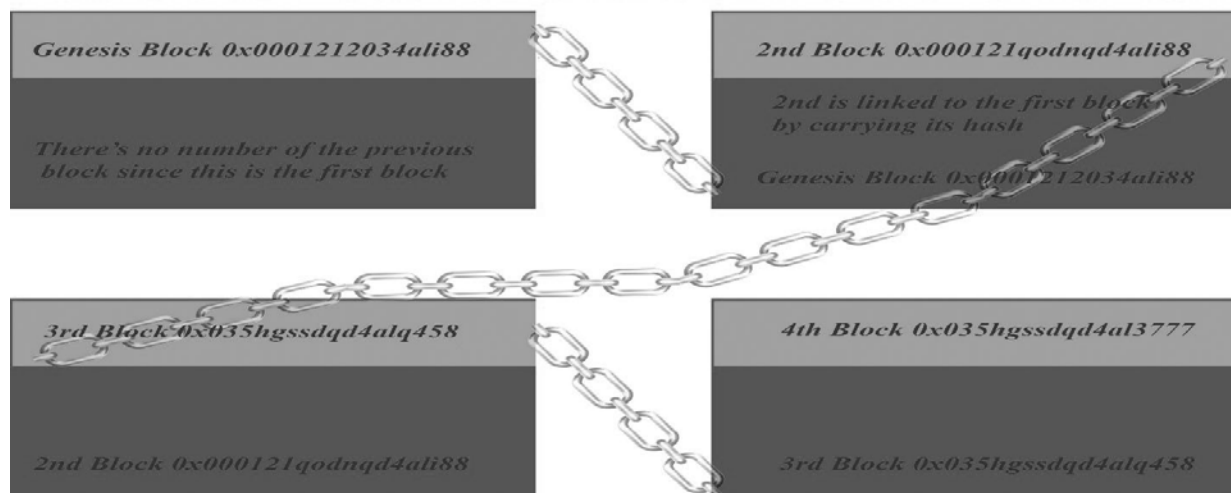
Figure 1. Double RSA.

Where there will be two public keys instead of one and four private keys instead of two creating to channels or tunnels for every node; where one of them will be used for sending information and the other one for reception.

### **Distributed ledger concept of Blockchain algorithm.**

Blockchain is a promising technology and we have published an essay about that [12], it is a public ledger with a distributed feature that behaves like a log which could keep track of all transactions in a chronological way, it is secured using a mechanism of appropriate consensus and provides an immutable record [13]. Therefore, it is possible to say that the blockchain could be considered as a decentralized ledger for all peer-to-peer network's transactions. With blockchain, participants could conduct transactions' confirmation without any need for a controlling central authority. Potential usage applications could be trade contracts, voting, fund transfers, etc... [14]. The blockchain technology could be exploited for securing network configuration updates exchanged between multiple controllers in SDN structure, but in a different way than it is used in the Marconi protocol [15].

*Every block contains hashed data and the combination of the hashed block's number hashed content is hashed as well to create a block ID that will be used to link the blocks together*



**Figure 2.** Blockchain.

### **3. Modelling the proposed topologies with petri nets**

In the beginning, it is important to give a simple description of the proposed topologies for software-defined networks' environment, that could be a better solution to deal with DoS/DDoS attacks.

Carl Adam Petri was accredited for the invention of Petri nets system and its aim is for describing chemical processes. The Petri Nets is a place/transition (PT) system; and it is a description and a modelling approach for distributed systems. Moreover, it has the definition of a dynamic system of discrete events. Petri Nets are directed bipartite graphs, therefore they're formed of two types of nodes. The two main nodes are places drawn as circles and transitions as bars. Those directed arcs define the direction of procedure and that would figure out which places are pre conditions and which are post conditions. The Petri Net presents a notation of a graphical nature that could be leveraged for diverse purposes and procedures with concurrent implementation. Also, this procedure presents a mathematical definition [3].

There are different types of simulation software that use petri net models so, it is possible to use one of the available choices we have; our choice here is the software named Platform



Independent Petri Nets Editor (PIPE). One of its main modules that we'll use for our own research is the Generalized Stochastic Petri Nets (GSPN) module that mainly focuses on what we exactly require and that's the amount of tokens that occupy the places which in turn represent the controllers placed in the SDN environment. The tokens here represent the updates or requests to or from the SDN controllers.

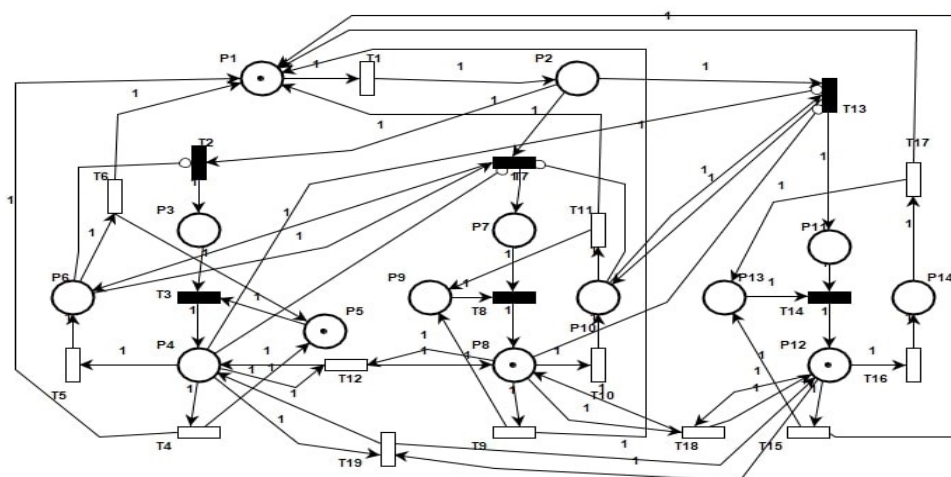
Now we are going to demonstrate how the three proposed topologies of controllers work, intercommunicate, and react towards each other. Also, we'll show how they defend themselves to deter different attacks like DoS/DDoS ones by modelling their behavior with petri nets system that uses Markov chains for modeling the behavior of the controllers in each topology. We will use the PIPE software to implement our topologies in petri nets, especially the module of GSPN to gain numerical results. The (GSPN) module, which stands for Generalized Stochastic Petri Nets, is defined as a 6-tuple  $(P, T, F, W, M_0, \lambda)$  [3] such that:

1.  $P = \{P_1, P_2, \dots, P_m\}$  describes the places' set  $n \geq 0$  which are of finite nature.
2. While  $T = T_1 \cup T_2$ ,  $T_1 = \{t_1, t_2, \dots, t_m\}$  describes finite timed transitions' group, and each one of those transitions has a delay time of a random nature the delay time is set within the period of enabling or activating and firing. In addition,  $T_2 = \{t_{m+1}, t_{m+2}, \dots, t_n\}$  is the finite immediate transitions' group or set, these transitions can be randomly fired and the delay value is set to zero.
3. Also,  $F \subseteq (P \times T) \cup (T \times P)$  is arcs' set; and, there are the inhibitor arcs which can only form places to transitions and disable the activated conditions.
4.  $W$  represents the arcs' weight function:  $F \rightarrow \{1, 2, 3, \dots\}$ .
5. Also,  $M_0: P \rightarrow \{0, 1, 2, 3, \dots\}$  represents the initial marking, where  $(P \times T) = \emptyset \cap (T \times P) = \emptyset$  [3].
6.  $\lambda = \{\lambda_1, \lambda_2, \lambda_3, \dots, \lambda_n\}$  represents firing rates' set that represent or describe the timed transitions. Each rate is the average firing times of transition in unit of time [3].

There three topologies presented in our research plus a fourth which is the single-controller Ordinary Topology. We'll compare the three topologies with the ordinary topology to depict the enhancements they have.

### Serial topology

As shown in the figure below, this topology consists of three controllers interacting with each other and communicating as one main controller and two controllers as backup; we should mention that they could be software-oriented or hardware-oriented controlling entities.



**Figure 3.** Proposed Serial Topology for Software-Defined Networks.

In this topology, the selected controller to work as the main controller is working normally and behaving as the decision-making node. This unit administrates the behavior of the network; communicating with the upper layer which is the management layer and with the lower layer which is the data layer and providing management for hosts' requests through the switches of the data plane.

The main controlling unit will send configuration updates and flow tables information of network every period of 10 seconds to the spare controllers to keep them up to date, to keep them as standby network controllers and to be able to continue administering and preserve the network information in case of a cyber-threat that could compromise the previous controlling node.

Again, after compromising the main node in the attack situation; the network management is going to be assigned to the standby controller that has the next number of priority, No. 2 controller for instance is going to be the one in charge in this situation. The next step will be sending a bot to infect the source IP of the attacker afterwards; this source IP of the attacker is going to be added to the blocked IPs in a single direction so the attacker can't send anything anymore just like the access control list (ACL) situation. The compromised controlling node is going to be isolated in the same time. The new elected controller will be the main one after it was the backup one previously. Now this controller administers the environment and exchanges network information with the other last remaining spare controller while the previously main controller is under maintenance. Table 1 provides Petri Nets places' description of the proposed Serial Topology model [6].

Table 1

Description of Places in Serial Topology for SDN	
Place	Description
P1	Packets being processed by the main controlling node / the input place which sends data tokens
P2	Servers' selection
P3/P7/P11	Servers' allocation
P4/P8/P12	Active processing in the servers 1,2,3
P5/P9/P13	Free controllers 1,2,3
P6/P10/P14	Attack is active

The table 2 depicts the serial model transition' description [6].

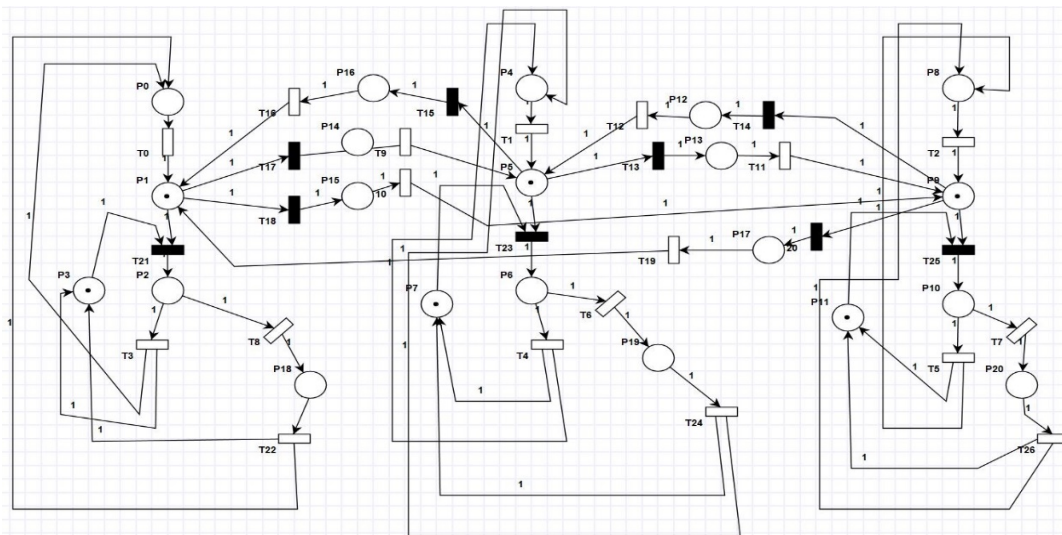
Table 2

Description of Transitions in Serial Topology for SDN	
Transition	Description
T1	Task generation i.e., processing of packets
T2/T7/T13	Selection of servers 1, 2, 3
T3/T8/T14	Allocation of servers
T4/T9/T15	Task processing
T5/T10/T16	Exiting the stage
T6/T11/T17	Restoring the controller
T12/T18/T19	Updating the information and going back to initial stage of controllers

### Parallel topology.

This topology consists of three main controllers; which cooperate in managing the whole network as a one entity as if it was one controller. They update each other with the information they have about the contiguous network nodes each controller has as shown in figure 4.

As mentioned before in this topology we'll have 3 controllers as well but, the difference will be in their interaction with each other. The 3 controllers will be working as a whole entity like one brain of 3 parts where they work simultaneously to process switches' requests. They will all behave like the main controller. Each controller will serve switches and prioritize them based on the closest ones to it. Each one of them will send a broadcast update to other remaining servers/controllers of its configuration every 10 seconds as well.



**Figure 4.** Proposed Parallel Topology for Software-Defined Networks.

Since all the three controllers represent a whole one main controller and the updates between the controlling entities will be every 10 seconds, that means that the configuration information will be merged together every 10 seconds, in other words the main triple-parts controller will update its general table of the whole network's status every 10 seconds. In case if there was a disruption on any one of the controllers, the other two controllers will fill the vacancy, left by the infected controller; and that's by serving the switches that were depending on the disrupted controller before it was disrupted. Of course; the switches will already be connected to all the three controllers so, in case of an attack; a bot that is already installed in the controllers; is going to be infiltrating the attacker's source IP. The attacked controller's IP will be isolated with the source IP of the attacker. Now all switches will be communicating with the controllers directly without any noticeable change, since that the remaining two controllers will add more space to deter Dos/DDoS attacks first and if this fails then the infected controller's IP will be isolated and the controllers continue their work like one controller of two main parts. The description of places is stated in the table 3.

*Table 3*

**Description of Places in Parallel Topology of SDN**

Place	Description
P1/P5/P9	Allocation of servers
P2/P6/P10	Server 1, 2, 3 Active processing

Continuation Table 3

P12-P17	Exchanging the information and configuration updates of the network
P3/P7/P11	Recovery and restoring the working state of the controller
P18/P19/P20	Attack on the server or controller
P0/P4/P8	Returning to the initial state

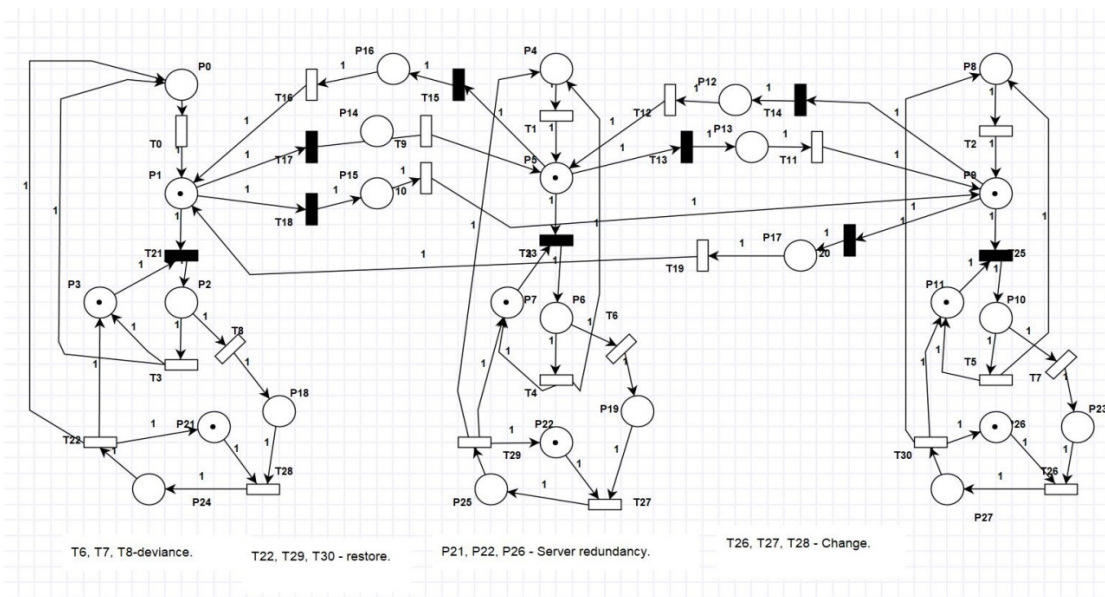
Description of transitions is in table 4.

Table 4

Description of Transitions in Parallel Topology of SDN	
Transition	Description
T21/T23/T25	Server 1, 2, 3 Active processing
T9-T20	Exchanging the updates of network configuration between servers
T3/T4/T5	Back to active processing/ processing the next request
T6/T7/T8	Attack on server/controller
T22/T24/T26	Recovery from the attack
T0/T1/T2	Transition back to initial state

**Hybrid topology.**

The Hybrid topology contains six controlling nodes; three primary controllers and three spare ones as backup. Every main controller has a backup controller that could be the next dominant primary controller in the situation of a disruption or a threat on its own current main controlling entity. As shown in design 5.



**Figure 5.** Proposed Hybrid Topology for Software-Defined Networks.

In addition, this topology can be considered as a mixture of the Serial and Parallel topologies, therefore it was named as Hybrid; the Hybrid topology's structure consists of six controlling nodes. Three of those six are main controllers working together in a parallel way as whole one brain and in this aspect this topology resembles the parallel topology therefore,

in this situation; the same rules of parallel topology can be applied [8]. The rest of the six controllers which are three will be considered as a backup for the main controlling nodes meaning, one backup controller for every main controller. The backup controllers will be connected to other network nodes as well and that's done via two ways:

- Being in connection with its main primary controlling node to take its place in the cyber-disruption or attack situation.
- Also, every single back controller will have a connection channel with everyone of the other backup or spare controlling nodes.

In critical situations of a disruption on any of the three main control layer nodes; then it will be blocked by isolation alongside with the perpetrator's source IP and it will be replaced with its substitute until the compromised previously main controller is back to work. Not to forget that prior to conducting this process; there will be an embedment of a bot within the source address of the attacker. The table 5 describes the places of this diagram [8].

Table 5

Description of Places in Hybrid Topology of SDN	
Place	Description
P1/P5/P9	Allocation of servers
P21/P22/P26	Extra servers / backup servers
P2/P6/P10	Active processing
P18/P19/P23	Server/controller under attack
P24/P25/P27	Recovery of server/controller
P3/P7/P11	Processing next request
P0/P4/P8	Returning to initial state
P12-P17	Exchanging the information across the network

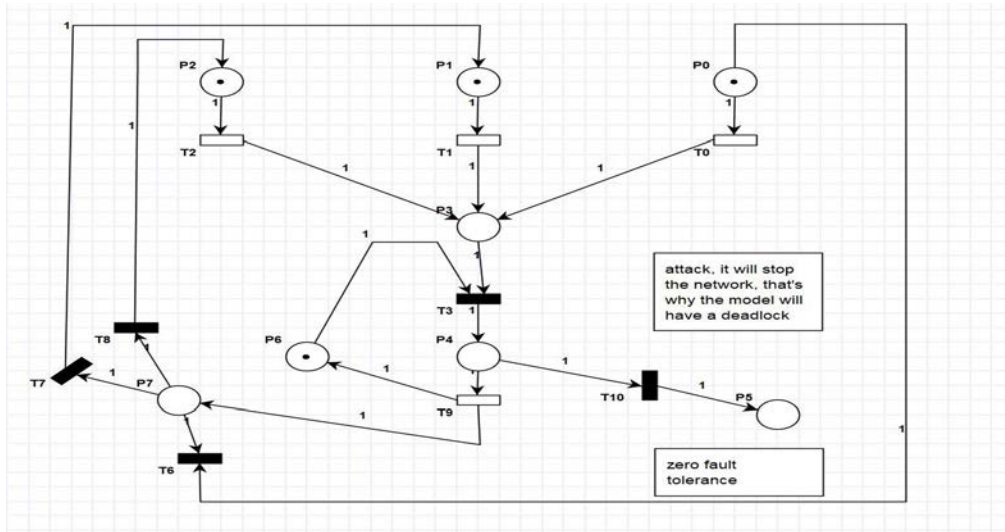
The table 6 describes the transitions of the hybrid topology in the model of Petri Nets [8].

Table 6

Description of Transitions in Hybrid Topology of SDN	
Transition	Description
T0/T1/T2	Transition from initial state to active processing
T21/T23/T25	Active processing
T3/T4/T5	Processing next request
T6/T7/T8	Deviance or attack state
T22/T29/T30	Transitioning to backup /restoring/ back to initial state
T26/T27/T28	Transformation and change
T9-T20	Sharing and updating the network configuration between servers

### Ordinary topology

This modeling is conducted for representing the usual single-controller topology that has the name; the Ordinary topology in our research which has one controller and for describing its weakness points.



**Figure 6.** Proposed Ordinary Topology for Software-Defined Networks.

This topology describes a simple single-controller environment of Software-defined network. It is being mentioned and modelled here for comparative analysis purposes to depict the reliability of the presented framework alongside its suggested three environments [8]. This diagram describes the vulnerability of single-controller SDN environment and how it is attack-prone due to the single point of failure SPOF issue; that needs to be patched. This network is managed via a single controlling entity that deals with switches' requests as usual until an attack occurs. In the attack situation any kind of disruption, the aforementioned model proves that a simple attack focused on that only controller could jeopardize the whole network. That shows that this single-controller environment has a fault tolerance of zero value. The Table 7 depicts the single-controller diagram's places [6].

*Table 7*

Places description in Ordinary Topology of SDN	
Place	Description
P0/P1/P2	Selection of switches
P3	Main controlling node
P4	Active processing
P6	Next request Processing / return to the initial state
P7	Exchanging requests
P5	Compromise attempt on the controller

The table 8 describes transitions of Ordinary topology in a Petri Nets model [6].

*Table 8*

Description of Transitions in Ordinary Topology of SDN	
Transition	Description
T0/T1/T2	Providing the controller with requests
T3	Active processing
T9	Initial state/ dealing with switches
T6/T7/T8	Selection of switches
T10	Attack attempt

By conducting a simulation in the PIPE software using the GSPN module on the above models; it is possible to gain the tokens' average number in that lies in every controller to derive a mathematical relationship between the used topology's type and the average number of tokens that represent that requests dealt with by each place that represents a controller. In addition, it is obvious that the bigger the number of tokens or requests; the less the defense ability the controllers will have so that means that defense factor value has an opposite proportion to the number of tokens. One more thing to notice that the proposed mathematical relationship has to show the same results gained by the PIPE software which clearly state that the parallel topology is the best amongst all of the other topologies since it has the least average number of token/requests per unit of time and that what we have to model mathematically. Table 9 describes the tokens' average number in places/controllers in the models of the Petri Nets topologies [6], [8].

Table 9

**Average Tokens' number in SDN Controllers represented by PN Places in GSPN Module**

Algorithms Places	Serial Topology	Parallel Topology	Hybrid Topology	Ordinary Topology
P3	0.16337			1.99975≈2
P7	0.06867			
P11	0.13233			
P1		0	0	
P5		0	0	
P9		0	0	
P21			0.9037	
P22			0.90368	
P26			0.90352	

The needed and created mathematical relationship is a relationship that could achieve the same results, as it will be shown afterwards. This relationship proved that based on the gained numerical results; it could be inferred that all the newly proposed three topologies work and behave better than the single-controller ordinary topology. Especially, the Parallel topology that is the ideal one theoretically and, from the mathematical relationship that was suggested in this research; we could acquire the same results and implications that match the acquired numerical results from the aforementioned simulation.

So, based on the simulation results, we propose an equation that represents the relationship between the number of controllers, type of interaction between them and the number of requests directed from/to them. The formula is derived to create a security factor that could be used a standard for determining the security intensity of any software-defined network that is leveraging any these three previously mentioned topologies [8]:

$$\Delta = \sum_{i=1}^{i=n} k_i \cdot \frac{1}{\sum_{z=0}^{z=\infty} z^{k_i}}$$

Where K is the places number or amount, which describe the work of the controllers in every model,  $K_i = (K_1, K_2 \dots K_n)$  and Z represents the number value of tokens in those places K of



those models. In addition,  $Z_{ki} = (0 \dots \infty)$ . Of course, the Higher the value of the Defense Factor, the better it is. By applying the gained simulation results, it is possible to find that according to the law the best topology would be the 2<sup>nd</sup> one or the parallel topology and that matches the simulation results shown in the table, that shows that the controllers in the 2<sup>nd</sup> topology will be less occupied with requests than other topologies which means that they will be more available hence; have more reliability against Dos/DDoS attacks.

The article's scientific value focuses mainly on figuring a method to find a measurement for the security proportion or intensity of any network environment that leverages any one of the aforementioned topologies. The article here depicted those topologies briefly and compared between them and the Ordinary topology.

The proposed formula's reliability and correctness is inferred from its matching to the simulation gained results. Because both the acquired results and the formula's implementation prove and assure that all the suggested SDN controllers' topologies work in a better way than the ordinary one. In addition, those topologies' controllers are freer along the average time of processing meaning that; they are less busy than the controller of the ordinary topology which means that those controllers be more reliable and more deterring to attacks like DoS/DDoS which focus on submerging the controllers with pseudo requests.

#### 4. Conclusions

We have presented in this article an idea about assuring the security of networks by assuring the security of software-defined networks hence, making it easier for classical structure networks to change to the SDN paradigm since it will be safer.

We discussed the main methods proposed to be integrated with the application layer as an application that will be a full framework to assure the security of SDN.

Alongside the proposed algorithms, here we explained briefly about the proposed working topologies in our research, that categorizes three main working topologies for software-defined networks' controllers.

Here we mainly focus on modelling the proposed topologies using Petri Nets system, to conduct a simulation on those modelled designs using PIPE software and to gain results that could show the best topology to be used with the emptiest space in its controllers; meaning the topology with the least vulnerable controllers to DoS/DDoS attacks. Based on the gained results we have created a mathematical relationship that will simulate the pattern of the gained results and their implications. This formula can be used as a theoretical mathematical instrument to figure out the cyber-threat level imposed on a network that leverages the SDN structure.

When we apply the acquired results from the simulation on this presented defense factor formula, the same implications could be gained. From the numerical simulation results, it is possible to conclude the following:

All the three proposed topologies are better than the usual one-controller SDN environment, which is the ordinary topology.

The parallel topology is the best of all four topologies since its controllers are emptier most of the average processing time.

And using the defense factor formula; it is possible to get a match for the gained numerical results which proves its feasibility.

The article's scientific value focuses mainly on figuring a method to find a measurement for the security deterrence level of any SDN that leverages any one of the



mentioned environments. This article depicted those topologies briefly and compared between them and the Ordinary topology.

The proposed formula's reliability and correctness is inferred from its matching to the simulation gained results. Because both the acquired results and the formula's implementation prove and assure that all the suggested SDN controllers' topologies work in a better way than the ordinary one. In addition, those topologies' controllers are freer along the average time of processing meaning that; they are less busy than the controller of the ordinary topology which means that those controllers be more reliable and more deterring against cyber-attacks which focus on submerging the controllers with pseudo requests.

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## THE INFLUENCE OF DEPENDENCES OF PSYCHOPHYSIOLOGICAL CHARACTERISTICS OF DRIVERS

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**Abstract.** The article analyzes the "man-machine-environment" system in relation to the psychophysiological characteristics of the driver - "human operator". The methods of diagnosing the psychophysiological characteristics of drivers were analyzed. The dependencies between the parameters of psychophysiological characteristics were established: complex visual-motor reaction and emotional stability (Pearson correlation coefficient  $r = -0.7$ ), as well as the correlation between emotional stability and the level of perception of speed and distance ( $r = 0.5$ ). The psychophysiological characteristics at different stages of the driving experience were revealed and practical recommendations were formulated for their development.

**Keywords:** *psychophysiological characteristics, professional important qualities, hardware and software diagnostic complex, monitoring, vehicle drivers.*

**Rezumat.** Articolul analizează sistemul „om-mașină-mediul” în raport cu caracteristicile psihofiziologice ale șoferului – „operator uman”. Sunt analizate metodele de diagnosticare a caracteristicilor psihofiziologice ale conducătorilor auto. Au fost stabilite dependențele dintre parametrii caracteristicilor psihofiziologice: reacție vizual-motorie complexă și stabilitate emoțională (coeficientul de corelație Pearson  $r = -0,7$ ), precum și corelația dintre stabilitatea emoțională și nivelul de percepție a vitezei și distanței ( $r = 0,5$ ). Au fost dezvăluite caracteristicile psihofiziologice în diferite etape ale experienței de conducere și au fost formulate recomandări practice pentru dezvoltarea acestora.

**Cuvinte cheie:** *caracteristici psihofiziologice, calități profesionale importante, complex de diagnosticare hardware și software, monitorizare, șoferi de vehicule.*

## Introduction

One of the priority areas of the state activity is ensuring road safety and creating an effective system for the prevention of road accidents. Driving a vehicle is complicated by the high traffic intensity and the presence of vehicle drivers with different levels of training in modern conditions.

These circumstances cause a significant increase in neuropsychic stress, which occurs in difficult, stressful conditions and require the body to adapt [1, 2]. They significantly increase the likelihood of developing negative changes in the psychophysiological functional state of a person, manifested in a decrease in the level of mental or psychophysiological adaptation and entail errors, as a result of which the number of road accidents increases.

According to statistics, about 70 % of road traffic accidents are the reasons of driver errors. Road accidents are the leading cause of death of people aged 15 to 29. The roads of European countries considered to be the safest, where the index does not exceed 10 people per 100 thousand population. The lowest rates are in the UK and Sweden (2.9 and 2.8 deaths per 100 thousand population) [3]. Also, car driver is the most risk profession of fatal injury index [4].

The article reveals the system "human-machine-environment" in relation to the psychophysiological characteristics of the driver, or "human operator", then "machiner" - a vehicle (car) and, accordingly, "environment" - external road, weather conditions.

Road safety is determined by the reliability of the whole system and the reliability of each of its components [5]. Failure of at least one element of the system can lead to a traffic accident.

We should note that one of the most important ensuring traffic safety skills of a driver is his speed of reaction – the natural response of the body to external influences [6].

The term "reaction time" may be defined simply as the time between a stimulus and a response. Any response of the body to a change in the external or internal environment: from the biochemical reaction of an individual cell to a conditioned reflex indicates reactions or quick decision-making.

The physical response time for most people while driving is about the same (average value 0.8 sec.), however, significant individual differences relate to the duration of the psychological response and range from 0.4 to 1.2 s. The high value of the reaction time increases the likelihood of an accident, which requires more attention while driving a vehicle [7]. The value of the reaction is not a constant value for a person and many factors can influence its final value. Some of them are individual characteristics of the organism, while others can change towards improvement.

The reaction time of the vehicle driver is one of the most important parameter while ensuring road safety [8]. At the same time, the driver's reaction is considered as a basic professionally important quality in the system of formation of human psychological activity.

Professionally important qualities (PIQ) - the qualities of the subject included in the process of activity and ensuring the efficiency of its implementation in terms of productivity, quality of work, and reliability. The importance of PIQ in ensuring the success of the development and implementation of professional activity is determined by the fact that they manifest the main characteristics of the personality structure, which determine the psychological characteristics of the system of activity [8].

Analyzing the actions of a driver when driving a vehicle, there are also five general PIQ of drivers necessary for safe driving: 1) the level of perception of speed and distance, 2)

assessment of the propensity to take risks, 3) distribution of attention, 4) assessment of emotional stability, 5) complex visual-motor reaction [9].

The main purpose of assessing the PIQ of drivers is identification of conditions contributing to an increase in emergency situations on the roads: inattention, distraction, emotional instability, rapid mental fatigue. Carrying out a researching of the psychophysiological state of a person-driver in the "driver-car-road-environment" system and searching for a correlation between individual parameters of the PVC will further develop recommendations for training on simulators, trainings, practical exercises for both beginners and experienced drivers, which will help reduce road accidents.

### **Experimental method**

The methodology of studying the psychophysiological state of drivers is based on assessing the speed of reaction to various stimuli and the accuracy of doing tasks. The assessment of psychophysiological characteristics was carried out by analyzing the following characteristics, measured by means of a hardware-software complex for motorists UPDK-MK (company "Neurokom", Russia) [9]:

- 1) General readiness for work. The test dynamically controls the functional state of the operator. With a low response time and a large number of errors, the subject is in a suboptimal functional state, which affects the increase in the time required for his relaxation.
- 2) Level of perception of speed and distance (LPSD) - the ability to correctly assess the speed of movement and the distance to objects in a rapidly changing traffic situation;
- 3) Risk-taking (RT) - tendency to commit unreasonable risky actions while driving;
- 4) Sharing attention (SA) - the driver's ability to simultaneously control and, if necessary, quickly and accurately perform the most important actions when driving a car, without losing control over other significant aspects of the road situation (manipulating controls, assessing the road situation, communicating with passengers, etc.);
- 5) Emotional stability (ES) - the driver's ability to drive adequately in the presence of interference and negative emotional factors;
- 6) Complex visual-motor reaction (CVR-M) - the ability to accurately and promptly respond to changes in the traffic situation (to traffic signals, road signs, maneuvers of other road users, etc.).

A participant in the experiment is in a sitting position at the computer during the test. One of the prerequisites was the creation of a friendly environment aimed at obtaining objective information about his individual psychological characteristics of responding to various signals.

The studies were carried out by 75 people, aged 19 to 30 years. The average age of the subjects was 24 years. Men accounted for 67% of the total number of subjects, women – 33 %. The participants in the experiment were divided into three groups (Table 1). Group I - candidates (with no driving experience); Group II - non-professional drivers with a driving experience of up to 4 years; Group III - non-professional drivers with more than 4 years of work experience. During the experiment, each participant was asked to pass 6 tests sequentially.

Before the beginning of the testing, the participant of the experiment registered and received an instruction to responsibly passing the test, studied the instructions, and proceeded to perform the preliminary test, according to the results of which the subject either continued or completed testing.

Table 1

Participants in the experiment			
Groups	Group size, people	Men, people	Women, people
I	25	17	8
II	25	16	9
III	25	17	8
Total	75	50	25

The target of this experiment is to determine the results of testing the values of psychophysiological characteristics in the form of marked level. Based on the methods, according to the results of passing the test, a grade of levels is conditionally assigned: D1 - the results of all 5 tests within the "norm"; D2 (D3) - "below the norm", ie the results of one (two) tests are outside the "norm"; and D4 - the results of more than three tests are outside the "norm".

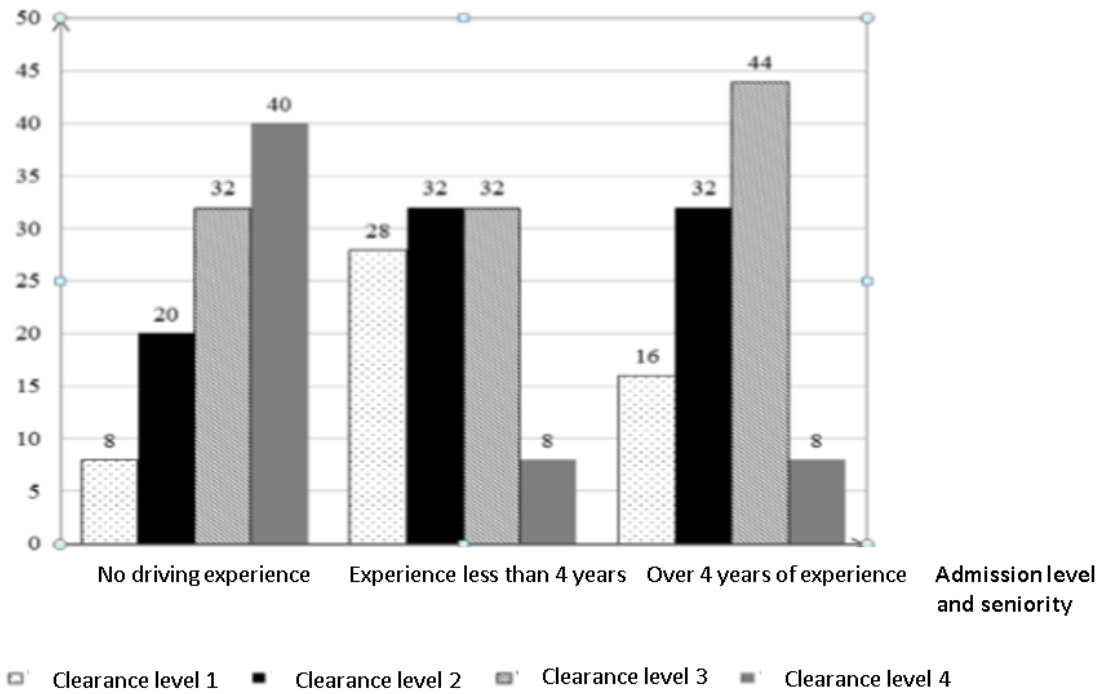
### Results of the research

The percentage distribution of participants in the experiment was assessed according to four types of tolerance in each Group, when passing a set of tests. The obtained assessments of the psychophysiological state showed the following results depending on the driving experience of the subjects (Figure 1). Participants in the experiment without driving experience (candidates, Group I) had only 8 % of the results corresponding to the D1 level; the same group had the lowest marks and received the most D4. Group II showed the highest result D1 (28%). Group II showed the greatest composure, responsibility, and desire to demonstrate high results D1. Group III had only 16 % D1 level. Perhaps due to the fact that as the subjects gain individual experience, there is a certain decrease in self-control due to excessive confidence and neglect of the accuracy of the tasks. The best results of the "normal" state were obtained by the participants of the experiment in all groups when passing Tests 2 and 5 ("Assessment of the risk-taking" and "Complex visual-motor reaction") (Figure 2).

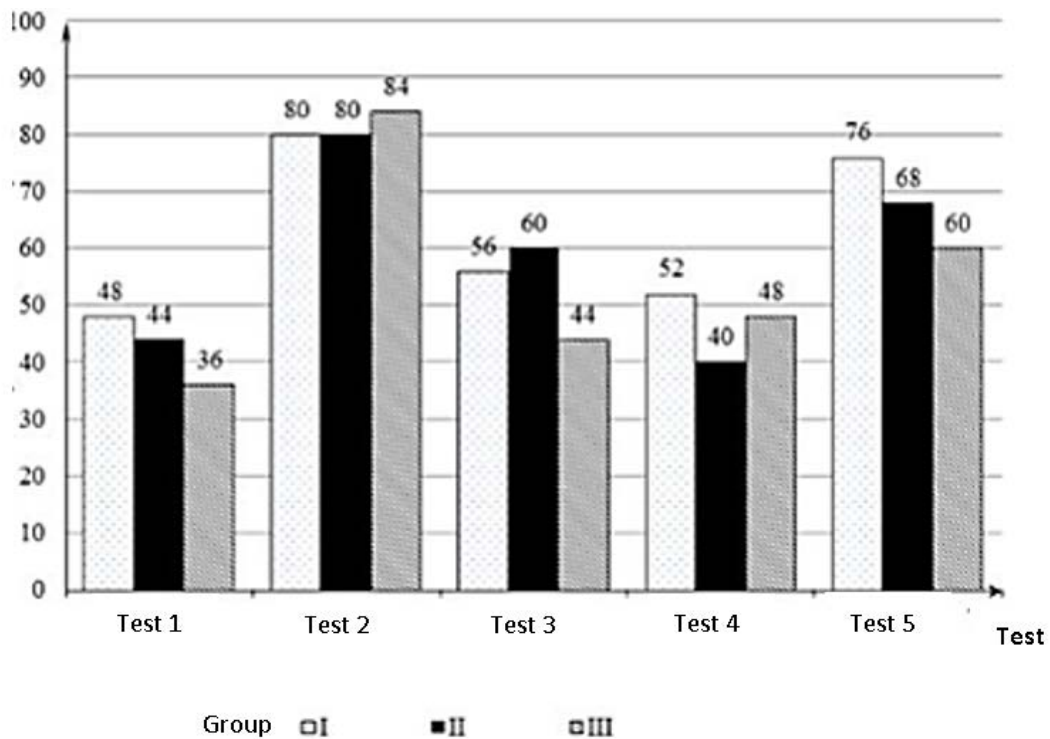
The results obtained were subjected to statistical processing. The analysis was carried out using the Pearson's correlation coefficient. Statistical analysis of the results of passing the tests by the participants in the experiment revealed a correlation dependence of some psychophysiological states. The average level of dependence of risk propensity on driving experience (Pearson's correlation coefficient  $r = 0.55$ ) and an inverse relationship between the assessment of "Sharing attention" and "Complex visual-motor reaction" ( $r = -0.62$ ) were revealed. A complex dependence of the assessment of "Complex visual-motor reaction" and "Emotional stability" ( $r = 0.75$ ) was revealed. The percentage distribution of the participants in the experiment is shown in table 2 with vulnerable (below normal) psychophysiological states. "Level of perception of speed and distance" and Test-4 "Assessment of the risk-taking" in the presence of driving experience (Groups II and III).

The assessment of emotional stability can be in some area of interest (Test 4). Emotionally unbalanced drivers are much more likely to violate traffic rules and participants in road accidents.

The emotional state is of great importance in the activities of the driver of the vehicle and in many cases determines the correctness and accuracy of his actions.



**Figure 1.** Results of passing tests by experiment participants by type of admission, %.



**Figure 2.** Results of assessments "norm" by three groups of participants in the experiment.

The vehicle driver may have negative emotions associated while driving a vehicle, in addition to the experiences inherent in each person. The reasons for these emotions can produce dangerous situations on the roads, driving in poor visibility conditions, life and health responsibility for the passengers, the unsatisfactory condition of the road surface, poor meteorological conditions (ice, snow, blizzard, and rain), the need for sharp braking and a sudden change in the direction of movement from created traffic situation.

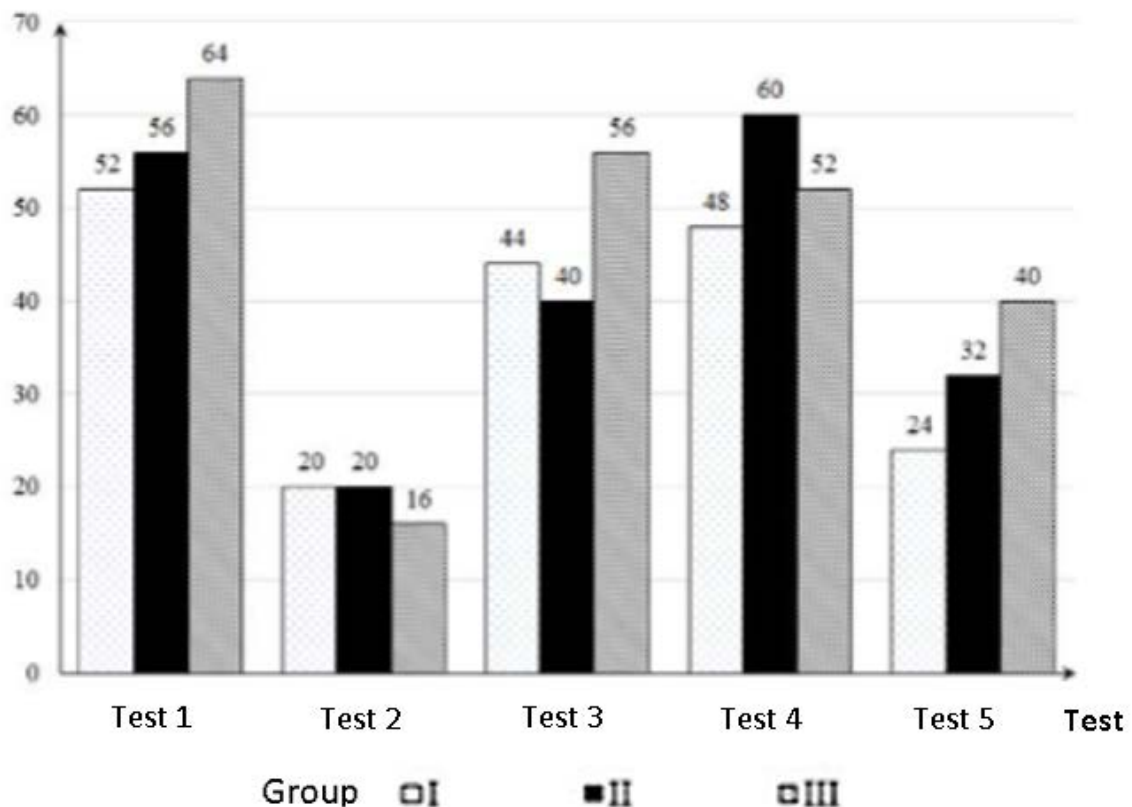
Table 2

**Percentage distribution of experimental participants with vulnerable (below normal) psychophysiological states**

Groups	Test 1	Test 2	Test 3	Test 4	Test 5
I	52	20	44	48	24
II	56	20	40	60	32
III	64	16	56	52	40

A high percentage of "not normal" grade was also established in all groups when assessing the distribution of attention (Test 3) (Figure 3).

**"Not normal", %**



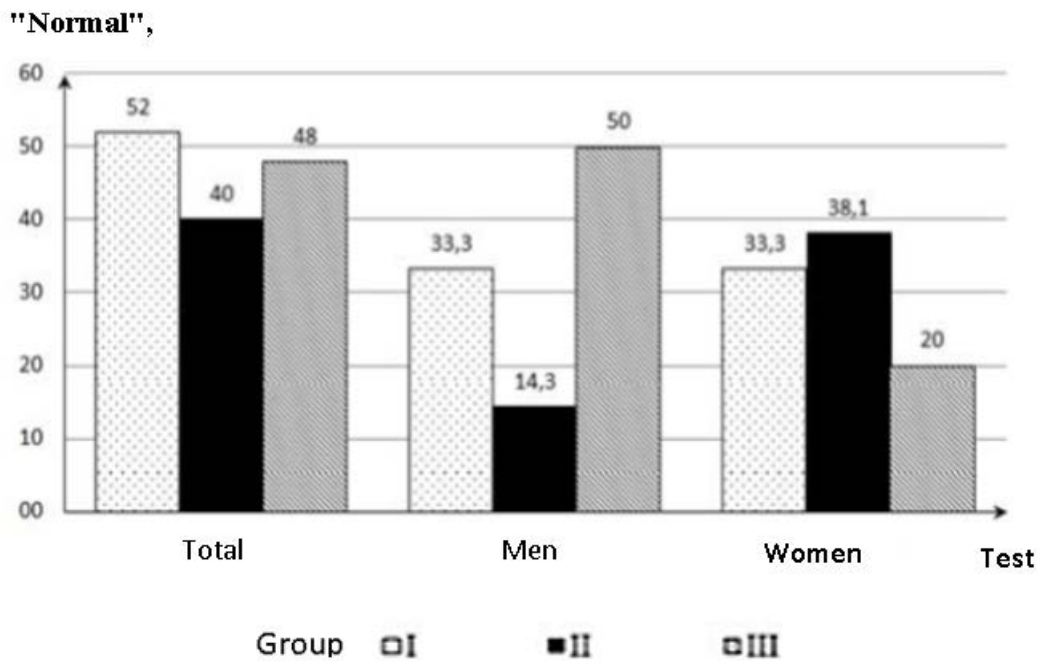
**Figure 3.** The results of assessing the psychophysiological state "not normal".

The main factor of vehicle driver emotional stress is the necessity of a constant assessment of the continuously changing road situation and in making decisions under conditions of lack of time [10].

The results of the test "Emotional stability" at different stages of the driving experience in Figure 4.

The graph shows that in mixed groups without taking into account the gender difference of the participants in the experiment, Groups I and III are the most emotionally stable. The participants in the experiment who do not have driving experience in Group I (not familiar with the experience of making emergency decisions in an emergency on the road) and drivers with experience in Group III are more emotionally "cold-blooded".

Group II is one of the interesting groups of drivers. Drivers of this group have driving work experience up to 4 years. Gender differences are taking into account.



**Figure 4.** Assessment of emotional stability.

The graph of assessing emotional stability shows decreasing of emotional stability in any group. It becomes inadequately low for men (they are more relaxed), and then it rises again to the level optimal for this activity (Group III of drivers). Women are more focused and have a high level of emotional stability in Group II, and in Group III they have a lower assessment of emotional stability (fear appears).

The results were statistically processed. The analysis was carried out using the Pearson's correlation coefficient. Statistical analysis of the test results by the participants in the experiment revealed a correlation dependence of some psychophysiological states.

As a result, a strong inversely proportional correlation was revealed between the parameters of psychophysiological characteristics: the average response time of the CVR-M and the indicator of the number of errors without EI interference ( $r = -0.70$ ). Based on this, we can conclude that the less time a driver spends when making a decision while driving, the more likely it is to make mistakes at the decision-making stage and when performing control actions in non-standard situations and in conditions of distraction.

A detailed analysis of the psychophysiological characteristics of drivers shows the average correlation dependence between the distribution of attention and emotional stability ( $r = 0.5$ ), as well as when assessing the LPSD, the number of exact hits has an average correlation dependence on the arithmetic mean of the ES response time ( $r = 0.5$ ). Which means: the higher the emotional stability, the more accurately the vehicle driver is able to assess the speed and distance while driving.

The correlation coefficient of indicators of emotional stability and complex motor response is given in Table 3.

### Conclusion

The analysis of statistical data on the results of assessing the level of the psychophysiological state of a person and data processing in order to determine the relationship of the mutual influence of various parameters of the psychophysiological state with each other. Thus, a strong inversely proportional correlation was found between the parameters of CVR-M and EI ( $r = -0.70$ ).



Table 3

**The correlation coefficient of indicators of emotional stability and complex motor response is given in the table**

CVR-M EI	Average response time per Task 1	Selection time	Average response time per Task 2	Difference in arithmetic mean response times
Number of errors without interference	-0.40	-0.55	-0.70	-0.56
Arithmetic mean response time without interference	0.42	-0.02	0.26	-0.03
Number of hindrances	0.42	-0.04	0.25	-0.04
Arithmetic mean response time with interference	0.36	-0.10	0.16	-0.10

The presence of a correlation dependence means that when training one type of psychophysiological qualities, a person unwittingly affects other correlation dependent psychophysiological characteristics. Research has also revealed that at different stages of the driving experience, you need to train different characteristics of the PIQ.

These conclusions will make it possible to take into account the dependence of the parameters of the PIQ and will become the basis for the development of practical methods of training drivers' skills in the future and will make it possible to develop recommendations: 1) to create simulators for both technical means and mobile applications; 2) to conduct practical training in driving schools when teaching driving skills; 3) to develop trainings for the acquisition and consolidation of specific skills PIQ driver.

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## COMPARATIVE ASSESSMENT OF COMPETENCE LEVEL OF TRANSPORT SYSTEM EXPERTS

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**Abstract.** The paper deals with the comparative assessment of competence level of transport system experts. The high level of competence of the experts is the premise to ensure the quality of the expertise of the systems insufficiently formalized from a mathematical point of view and characterized with a high degree of uncertainty. Six factors for assessing the competence of transport system experts were summarized. The values of the priority vector of the competence factors were established with the application of the Saaty algorithm and scale in nine points by the method of comparisons in pairs. The value of the concordance ratio of the experts' opinion for the prioritization matrix was calculated. The comparative competence coefficient of the experts in transport systems was calculated and the hierarchy of experts was established according to the value of the nominal coefficient.

**Keywords:** *transport, expert, factor, competence, level, calculation, hierarchy.*

**Rezumat.** Lucrarea abordează problema evaluării comparative a nivelului de competență al experților în sisteme de transport. Nivelul ridicat de competență al experților este premisa asigurării calității expertizei sistemelor insuficient formalizate din punct de vedere matematic și caracterizate cu un grad ridicat de incertitudine. Au fost sintetizați șase factori pentru evaluarea competenței experților în sisteme de transport. Valorile vectorului prioritar al factorilor de competență au fost stabilite cu aplicarea algoritmului Saaty și a scării în nouă puncte prin metoda comparațiilor în perechi. S-a calculat valoarea raportului de concordanță al opiniei experților pentru matricea de prioritizare. A fost calculat coeficientul comparativ de competență al experților în sistemele de transport și stabilită ierarhia experților în funcție de valoarea coeficientului nominalizat.

**Keywords:** *transport, expert, factor, competență, nivel, calcul, ierarhie.*

### Introduction

Developed and applied primarily for the optimization of forecasts in the field of science and technology, modern methods of expertise are finding an increasingly common application in the study of various economic and production systems.

The objective of the nominated methods is to combine the opinions of highly qualified experts to establish the optimal ways to develop the analyzed systems.

Expert research are of distinct significance and are usually used to validate operational logic and simulation results. This type of research methods is of major interest for the study of insufficiently formalized systems in mathematical terms, affected by the high degree of uncertainty and the contradictory action of external environmental factors [1], [2].

Transport systems are defined as the totality of elements (infrastructure, means of transport, operators, traffic management systems, etc.), interacting and integrated into the geographical space and the economic environment through multiple interdependent relationships. In order to adopt the most reasoned and crucial decisions regarding the development of transport systems, it is necessary to apply various informal methods, in particular modern methods of expertise.

In cases characterized by a high level of uncertainty, specific to modern transport systems, evaluations based on the experience, competence, elaborations, concepts, ideas, opinions and hypotheses of highly qualified specialists in the respective field can be used as realistic solutions [3 - 6]. Qualitative selection of experts in transport systems involves the use of the following main criteria: competence, objectivity, creativity, non-conformism, constructive thinking, teamwork, self-criticism, availability and professional interest [7 - 9].

Sometimes decision-makers in transport systems invite various specialists as experts in the field, whose competence is not analyzed compared to the level of other experts, included in the research group [4], [6].

The competence of an expert reflects the person's level of qualification in a particular field, which can be assessed as a result of the relevant analysis of his activity, the level and extent of knowledge of scientific and technological achievements, the depth of understanding the essence and root causes of problems, of the development perspectives of the researched sector [1], [2], [7].

The process of selecting the optimal number of competent experts for the synthesis of statistically stable solutions for transport systems is one of decisive importance.

Increasing the number of competent experts in the research group minimizes the likelihood of making wrong decisions and improves the quality of the evaluation [1], [8]. Improving the reliability of expert evaluations by attracting the most competent experts is the most important task.

From a scientific point of view, the issue of assessing the competence of experts is not considered to be definitively resolved [1], [7].

### **1. Comparative assessment of the level of competence of transport system experts**

In accordance with the generally accepted methodology, the selection of experts with the highest levels of competence from a group is made in the following sequence: 1) establishing the list of competence factors for the category analyzed by experts; 2) assessment of the competence of experts for the list established by factors based on objective criteria; 3) determining the priority hierarchy of competence factors; 4) evaluation of the comparative level of competence of the experts considering the priority of the competence factors; 5) choosing the experts with maximum values of the comparative coefficient of competence [7], [8].

The competence of experts in transport systems is proposed to be assessed with the following main factors: 1) the level of professional qualification; 2) practical experience in the field; 3) managerial experience corresponding to the level of expertise issues; 4) the number of scientific monographs in the field; 5) the number of scientific publications in the

field in journals with impact factor; 6) the number of participations in national and international projects in the field. The options for the answers for each proposed competence factor and the corresponding values of the weighting coefficient are presented in Table 1.

The methodology for comparative assessing of the level of competence of transport system experts based on the proposed competence factors is set out below. For each expert  $i$ , included in the group of specialists in transport systems, the individual score corresponding to each competence factor  $j$  is calculated with the following relation:

$$\sum X_i = \sum_{j=1}^n a_{ij} \quad (1)$$

For each competence factor  $j$  the summary score of all experts in the group is calculated, as well as the total score of all factors according to the formula:

$$\sum F_j = \sum_{i=1}^m a_{ij} \quad (2)$$

The value of the weighting coefficient  $C_w$  of each expert in the group for all competence factors is determined as follows:

$$C_w = \frac{\sum_{i=1}^m \sum_{j=1}^n a_{ij}}{\sum_{j=1}^n a_{ij}} \quad (3)$$

Table 1

**Values of the weighting coefficient  $C_w$  of the competence factors**

Competency factor	$C_w$	Competency factor	$C_w$
1.Level of professional qualification		4.The number of scientific monographs	
• Undergraduate studies	0,15	• 0	0,00
• Masters	0,25	• 1	0,20
• Doctoral studies	0,60	• 2	0,25
		• 3	0,30
		• 4 and more	0,35
2. Practical experience in the field		5. The number of scientific publications in the field in journals with impact factor	
• Up to 6 years	0,10	• 0	0,00
• From 6 to 10 years	0,15	• 1-5	0,20
• From 11 to 15 years	0,20	• 6-15	0,25
• From 16 to 20 years	0,25	• 16-25	0,30
• Over 20 years	0,30	• Over 25	0,35
3.Managerial experience in the field		6. The number of participations in national and international projects	
• Up to 6 years	0,10	• 0	0,00
• From 6 to 10 years	0,15	• 1-2	0,20
• From 11 to 15 years	0,20	• 3-4	0,25
• From 16 to 20 years	0,25	• 4-6	0,30
• Over 20 years	0,30	• Over 6	0,35

The results of the calculations based on relations (1)-(3) are shown in Table 2.

Table 2

Expert number	Competency factor number						$\sum X_i$	$C_w$
	1	2	3	4	5	6		
1	0,60	0,30	0,25	0,30	0,35	0,35	2,15	0,1886
2	0,60	0,25	0,20	0,25	0,30	0,30	1,90	0,1667
3	0,60	0,20	0,15	0,20	0,25	0,25	1,65	0,1447
4	0,25	0,30	0,25	0,00	0,20	0,20	1,20	0,1053
5	0,25	0,25	0,20	0,00	0,20	0,20	1,10	0,0965
6	0,25	0,20	0,15	0,00	0,00	0,00	0,60	0,0526
7	0,15	0,30	0,30	0,00	0,00	0,20	0,95	0,0833
8	0,15	0,25	0,25	0,00	0,00	0,20	0,85	0,0746
9	0,15	0,20	0,20	0,00	0,00	0,00	0,55	0,0482
10	0,15	0,15	0,15	0,00	0,00	0,00	0,45	0,0395
$\sum F_j$	3,15	2,40	2,10	0,75	1,30	1,70	11,40	1,0000

In order to increase the accuracy of the determination of the comparative level of competence of each expert, the values of the weighting coefficients in Table 2 are recalculated, using for this purpose the relation:

$$b_{ij} = \frac{a_{ij}}{\sum F_j} = \frac{a_{ij}}{\sum_{i=1}^m a_{ij}} \quad (4)$$

The results of the calculations based on relation (4) are shown in Table 3.

Table 3

Expert number	Competency factor number						$\sum X_i$	$C_w$
	1	2	3	4	5	6		
1	0,1905	0,1250	0,1190	0,4000	0,2692	0,2059	1,3096	0,2183
2	0,1905	0,1042	0,0952	0,3333	0,2308	0,1765	1,1305	0,1884
3	0,1905	0,0833	0,0714	0,2667	0,1923	0,1471	0,9513	0,1585
4	0,0794	0,1250	0,1190	0,0000	0,1538	0,1176	0,5949	0,0992
5	0,0794	0,1042	0,0952	0,0000	0,1538	0,1176	0,5503	0,0917
6	0,0794	0,0833	0,0714	0,0000	0,0000	0,0000	0,2341	0,0390
7	0,0476	0,1250	0,1429	0,0000	0,0000	0,1176	0,4331	0,0722
8	0,0476	0,1042	0,1190	0,0000	0,0000	0,1176	0,3885	0,0647
9	0,0476	0,0833	0,0952	0,0000	0,0000	0,0000	0,2262	0,0377
10	0,0476	0,0625	0,0714	0,0000	0,0000	0,0000	0,1815	0,0303
$\sum F_j$	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	6,0000	1,0000

To establish the values of the priority vector of the competence factors, the nine-point Saaty algorithm and scale and the pairwise comparison method are applied [10].

The prioritization matrix, presented in Table 4, reflects the integrated opinion of the group of experts in transport systems.

Table 4

Matrix of pair comparisons of factors (Prioritization matrix)								
$F_j$	$F_i$						Geometric mean	Priority vector $V_p$
	$F_1$	$F_2$	$F_3$	$F_4$	$F_5$	$F_6$		
$F_1$	1,000	5,000	2,000	0,200	0,500	0,500	0,89089	0,11828
$F_2$	0,200	1,000	0,500	0,200	0,333	0,500	0,38643	0,05130
$F_3$	0,500	2,000	1,000	0,200	0,500	1,000	0,68129	0,09045
$F_4$	5,000	5,000	5,000	1,000	3,000	3,000	3,22496	0,42817
$F_5$	2,000	3,000	2,000	0,333	1,000	2,000	1,41397	0,18773
$F_6$	2,000	2,000	1,000	0,333	0,500	1,000	0,93449	0,12407
$\sum F_j$	10,70	18,00	11,50	2,266	5,833	8,000	7,53203	1,00000

As the opinions of the experts in the selected group sometimes differ significantly, it is necessary to establish the specific level of concordance and the causes of the differentiation of the opinions of the specialists [1], [7], [8].

If the pair comparison method is applied, it becomes possible to assess the concordance of the experts' opinions, the concordance index for the given priority factor matrix being calculated with the following relation:

$$I_C = \frac{(L_{\max} - N)}{(N - 1)} = \frac{(6,286993 - 6)}{(6 - 1)} = \frac{0,286993}{5} = 0,0573986 \quad (5)$$

where:  $N$  is the number of competence factors, 6.

The maximum eigenvalue of the competence factor prioritization matrix is determined by the formula:

$$L_{\max} = \sum_{i=1}^n F_{ji} \cdot V_{Pi} = (10,7 \cdot 0,118) + (18,0 \cdot 0,051) + (11,5 \cdot 0,090) + (2,266 \cdot 0,428) + (5,833 \cdot 0,187) + (7,532 \cdot 0,124) = 6,286993 \quad (6)$$

The concordance ratio is determined by the relation:

$$R_C = \frac{I_C}{C_R} = \frac{0,0573986}{1,24} = 0,046289 \quad (7)$$

where:  $C_R$  is the random consistency coefficient, equal to 1,24 for  $N=6$  [7], [9].

As the  $R_C$  ratio does not exceed the limit value (0,2), clarification of expert evaluations is not necessary [11], [12].

The most important competence factors according to the prioritization matrix are the number of scientific monographs in the field and, respectively, of scientific publications in journals with impact factor.

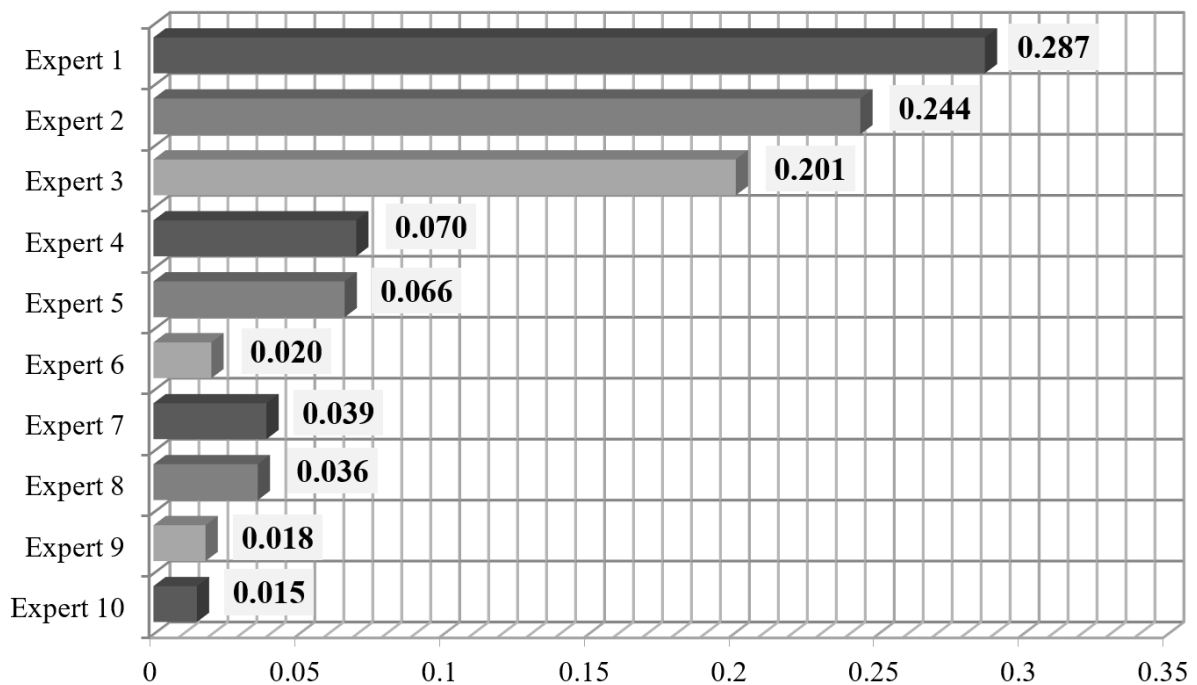
The final value of the competence coefficient  $C_C$  of each expert in the group sums the product between the values of the particular weighting coefficients  $C_{Wj}$  of each expert (Table 3) and the  $V_{pj}$  values of the priority vector of the respective competence factors (last column of Table 4).

Table 5

**Comparative coefficient of competence of transport system experts**

Expert number	Competency factor number						$\sum X_i$	$C_c$
	1	2	3	4	5	6		
1	0,0225	0,0064	0,0107	0,1712	0,0505	0,0255	0,28706	0,28706
2	0,0225	0,0053	0,0086	0,1427	0,0433	0,0218	0,24443	0,24443
3	0,0225	0,0042	0,0064	0,1141	0,0361	0,0182	0,20179	0,20179
4	0,0093	0,0064	0,0107	0,0000	0,0288	0,0146	0,07005	0,07005
5	0,0093	0,0053	0,0086	0,0000	0,0288	0,0146	0,06682	0,06682
6	0,0093	0,0042	0,0064	0,0000	0,0000	0,0000	0,02012	0,02012
7	0,0056	0,0064	0,0129	0,0000	0,0000	0,0146	0,03956	0,03956
8	0,0056	0,0053	0,0107	0,0000	0,0000	0,0146	0,03634	0,03634
9	0,0056	0,0042	0,0086	0,0000	0,0000	0,0000	0,01852	0,01852
10	0,0056	0,0032	0,0064	0,0000	0,0000	0,0000	0,01530	0,01530
$\sum F_j$	0,1182	0,0513	0,0904	0,4281	0,1877	0,1240	1,00000	1,00000

The hierarchy of experts in transport systems according to the value of the comparative coefficient of competence is shown in Figure 1.



**Figure 1.** Comparative coefficient of competence  $C_c$  of experts in transport systems.

The data in Figure 1 show that the highest values of the comparative coefficient of competence are characteristic of experts 1, 2 and 3.

## 2. Conclusions

Determining the comparative level of competence of transport systems experts in the initial group is useful and necessary because it allows the selection and inclusion in the selected group of the most competent specialists, so the qualitative expertise of the most complex cases can be ensured.

The practice of appointing experts with a modest level of competence as experts in transport systems should be removed from the work of decision-makers.

The elaborated procedure for assessing the comparative level of competence of transport system experts contributes significantly to the creation of the premises for solving a wide range of practical problems, characteristic of the transport industry.

The methodology is easily adaptable to the particularities of the object subject to expertise.

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## APPLICATION OF REGRESSION ANALYSIS IN FEASIBILITY STUDIES OF CONSUMER CONNECTION TO DISTRICT HEATING SYSTEMS

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**Abstract.** Nowadays, both globally and in Europe, and nationally, there is a tendency to promote district heating systems to the detriment of individual ones to heat dwellings in urban areas. The need to develop the DHSs is indisputable considering the topicality of global warming, the depletion of the primary energy resources and the energy efficiency trend. This article presents the method of applying regression analysis in feasibility studies for the projects of new heat consumers connection to the district heating system (hereinafter – DHS) or previously disconnected consumers reconnection via individual heating points (hereinafter – IHP) when the necessary investments are to be borne by the DHS operator, and the thermal energy is produced in cogeneration. At the same time, it is demonstrated that there is a direct and linear correlation between fuel consumption and electricity and heat produced in cogeneration at CHP plant.

**Keywords:** *cogeneration, domestic hot water, equation of a straight line, heating season, individual heating point, regression analysis.*

**Rezumat.** Astăzi, atât la nivel mondial și european, cât și la cel național, există tendința de promovare a sistemelor centralizate de energie termică în detrimentul celor individuale, pentru încălzirea locuințelor în mediul urban. Luând în considerație actualitatea problemei încălzirii globale și celei legate de epuizarea resurselor energetice primare, cât și a tendinței eficientizării consumului de energie, necesitatea dezvoltării SACET-urilor este incontestabilă. În această lucrare este prezentată metoda aplicării analizei de regresie în studiile de fezabilitate pentru proiectele de conectare a noilor consumatori de căldură la sistemul centralizat de alimentare cu energie termică (în continuare - SACET), sau reconectarea consumatorilor anterior debransați, prin intermediul punctelor termice individuale (în continuare – PTI), în cazul în care investițiile necesare urmează a fi suportate de operatorul SACET, iar energia termică este produsă în cogenerare. Totodată, este demonstrat faptul că între consumul de combustibil și volumele de energie electrică și termică produse în cogenerare la un CET, există o corelație directă și liniară.

**Cuvinte cheie:** *analiză de regresie, apă caldă menajeră, cogenerare, ecuația liniei drepte, punct termic individual, sezon de încălzire.*

## Introduction

DHS represents a unitary technological and functional ensemble that includes buildings, installations, equipment, specific facilities, and measurement equipment intended for the generation, transmission, distribution, and supply of thermal energy to consumers, respecting efficiency and quality standards [1].

Suppose a DHS is well designed, built, maintained, and constantly developed by implementing the latest and most efficient technologies for production, transmission, and distribution of heat, and consumers pay bills for heating service. In that case, this system can provide quality services at cost small or at least equal to those offered by individual alternative heating solutions and with a much smaller impact on the environment and human health [2].

The most important benefits of district heating, compared to the individual heating systems are less impact on the environment and human health and greater economic efficiency [3 - 4]. The use of DHS compared to individual heating systems allows easier replacement of fossil fuel use with renewable energy sources [5], municipal solid waste, as well as the use of residual heat from other industrial processes [6]. However, the limited comfort of the apartments connected to the DHS, influenced by the way how the system can react to variable loads, represents a disadvantage of using these types of heating systems [7].

To ensure the continuity of quality service providing to consumers, DHS must constantly carry out maintenance and investment measures, with emphasis on the development of solutions, technologies, command and control elements, software packages with higher performance than existing ones, both at the level of production, as well as energy transmission and distribution.

The modernization solution is more advisable than the rehabilitation of an existing DHS. This avoids the risk of maintaining a worn-out system, with modest performance and unprofitable, unable to meet current requirements imposed by the energy market [2].

The modernization/development measures in the DHS can be applied:

1. *at the heat source:*

- high-efficiency cogeneration production technologies;
- efficient combustion and low pollution boilers;
- pumps with variable speed drives;
- automation, safety, and intelligent monitoring systems;
- heat recovery installations;
- metering of all energy flows, etc.

2. *in the transmission and distribution networks:*

- pre-insulated pipes with damage signalling system;
- pumps with variable speed drives;
- separation valves with remote electric drive, equipped with measuring and control armature with remote data transmission;
- modern, and high-reliability closing and adjustment armature, etc.

3. *at the heating points:*

- central heating points conversion to IHP installed in buildings;
- high-efficiency and reliable heat exchangers;
- pumps with variable speed drives;
- metering of all energy flows with remote data transmission, etc.

4. *at the consumers' side:*

- IHP installation [8];
- buildings thermal insulation and sealing;
- transition from the vertical heat distribution system to the horizontal distribution system in the internal buildings' heating systems;
- heat and hot water meters installed in each apartment, etc.

In the Republic of Moldova, according to the legal requirements, the investments specified in points 1-3 must be made by the DHS operator and those in point 4 - by the consumer. However, the DHS operator, on the one hand, and the consumers, on the other hand, must represent a partnership, which operates efficiently with common goals and interests.

This article is focused on the economic efficiency evaluation of the modernization projects involving the installation of an IHP.

### ***IHP - a modern solution for the heat consumption streamlining at consumers***

The individual heating point is a set of equipment that provides:

- automatic mode building's heating, with the possibility of the thermal agent temperature automatic adjustment, based on the outdoor air temperature inclusively;
- domestic hot water preparation directly in the building perimeter, thus improving the domestic hot water (DHW) quality.

The IHP installation at the residential block level offers consumers the following advantages:

- heat costs reduction by at least 10%;
- indoor thermal comfort corresponding to the outdoor air temperature, by automatically thermal agent temperature adjustment in the internal heating system depending on the outdoor air temperature;
- preparation of the DHW in building, non-stop at quality parameters;
- safety against explosions and contamination with harmful emissions;
- the possibility to connect/disconnect the building heat supply at the consumer's request;

and to the DHS operator:

- losses reduction associated with the hot water supply;
- DHS image and attractiveness enhancing;
- business stability and more efficient planning.

In the Chisinau DHS, the first IHPs have been installed since the 2003-2004 years. So far, around 900 IHP were installed, which is approx. 21% of all buildings that is appropriate to equip with IHP. At the same time, it is recommended to connect to the DHS the new consumers or those reconnected after having before disconnected from this system for various reasons via IHP. However, the operator's decision to invest in installing an IHP in a building that is planned to be connected/reconnected to the DHS must be argued by a feasibility study. The study should be based on an economic profitability calculation of the connection project, carried out correctly, taking into account all the necessary investments and the benefits obtained as a result of the sale of an additional amount of thermal energy.

In many DHS, the thermal energy is produced in cogeneration mode. The major motivations for considering cogeneration systems are the potential savings in money and

energy, and the potential for lower emissions [9]. Therewith, cogeneration is a technique for generating multiple energy products simultaneously in a manner of utilizing high-exergy flows for processes where they are needed and the remaining low-exergy flows where they can be used. Thus an important reduction in irreversibility is achieved in comparison with the separate generation of these products [10].

Of the total thermal energy supplied to consumers connected to Chisinau DHS, about 80% is produced from cogeneration by the combined heat and power (CHP) plants. In this case, in calculating the economic profitability of connecting a new heat consumer, it is necessary to consider both gains due to additional sales of heat and those related to the sale of electricity produced in cogeneration when assessing revenues.

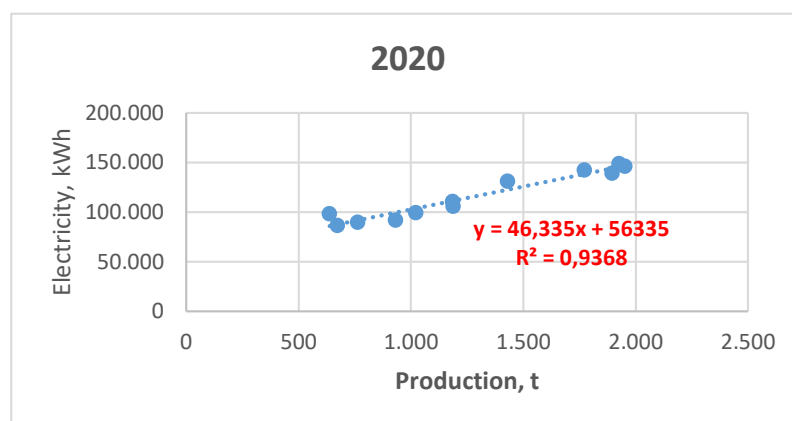
### **The regression analysis theory**

The statistical methodology is focused on the regression function to determine the parameters that express to what extent one or more factors influence a variable or process. The estimation of the function parameters that describe the dependence between effect ( $y$ ) and factors ( $x$ ) is done by using the regression method. The linear regression method can be successfully applied in the energetics analysis and is used when for a data set represented by pairs of values  $(x_i, y_i)$ , the line that best approximates their placement in the diagram must be found  $y = f(x)$ .

If the variable or process  $y$  is influenced only by one-factor  $x$ , then simple regression analysis (with a single variable) is applied. For example, it is assumed that there is a linear dependence between two variables, such as the electricity consumed by an enterprise and its production volume. Using the respective data collected over a long time, they can be represented graphically in a diagram of electricity consumption =  $f(\text{production volume})$ . The points thus obtained are arranged approximately linearly and must determine the line that best approximates the sequence of points, i.e., to find the equation of the form  $y = bx + c$ , which describes a dependence between discretely represented data. In the considered example, the independent variable  $x$  is the production volume during each month of 2020, and the dependent one  $y$  is the electricity consumption for each month (Figure 1).

By applying Eq. (1), for any value of the production volume, it is easy to determine the corresponding electricity consumption:

$$y = 46,335x + 56335. \quad (1)$$



**Figure 1.** Regression analysis of electricity consumption according to production volume.

The  $R^2$  value is also significant in determining the dependence intensity of the correlation between the two variable values. The closer to 1 the  $R^2$  value is, the more the

variation of the value  $x$  explains the interpretation of the value  $y$ . The  $R^2 = 0,9368$  (Figure 1) analysis results that in 2020, the volume of production influenced the enterprise's electricity consumption.

So, the straight-line equation can be used to predict electricity consumption for any variable (driver):

$$\text{Energy}(y) = \text{Factor} \cdot \text{Driver}(x) + \text{Constant}. \quad (2)$$

If the variable or process  $y$  is influenced by several factors  $x_1, x_2 \dots x_n$ , then multiple regression analysis (with two or more variables) is applied.

The linear regression technique must be used with caution, as it can lead to erroneous conclusions. If the data participating in the analysis are lacking, then the conclusions drawn based on an insufficient data set have a low degree of credibility. The more data we have, the higher the degree of trust.

The essence of the linear regression method application to predict the energy produced or consumed depending on certain factors is described in the articles of many researchers. For instance, the article [11] describes the method of multiple regression analysis to predict energy consumption in buildings depending on the outside temperature and the occupancy level of these buildings. The article [12] demonstrates that a country's energy consumption can be predicted by applying the same regression analysis using historical data for the following factors: installed electric capacity of power plants, electricity consumption, heat consumption, population, investments in electric power industry (including district heating, gross domestic product (GDP) and time interval.

### ***The methodology applied for economic efficiency evaluation***

In the following, the methodology for the economic efficiency evaluation of the new consumers' connection to the DHS, or previously disconnected consumers reconnection, by connecting the consumers' internal heating system to the heating networks of DHS, through an individual heating point, when the thermal energy is produced from cogeneration at a combined heat and power (CHP) plant.

One of the primary criteria that can be used to assess the economic efficiency of such a project is the *simple payback period* - DR, which expresses the number of years during which the initial investment is recovered from the annual income from the project:

$$DR = \frac{I_{tot}}{V_{net.an}}, \quad (3)$$

where  $I_{tot}$  – total project investments;  $V_{net.an}$  - annual net income.

For the project to be considered cost-effective, the simple payback period must be at the level allowed for similar projects and shorter than the lifespan of the project [13]. The lifespan for IHP can be considered as 20 years.

The total investment in the project will be determined with the following formula:

$$I_{tot} = I_{HN} + I_{IHP}, \quad (4)$$

where:  $I_{HN}$  - investment for the heating network acquisition and installation;  $I_{IHP}$  - investment for the IHP acquisition and installation.

The annual net income obtained as a result of the project implementation will be determined with the relation:

$$V_{net.an} = V_{brut.an} - C_{an}, \quad (5)$$

where:  $V_{brut.an}$  - annual gross income;  $C_{an}$  - annual expenses.

In case of investment in the connection/reconnection projects or installation of an IHP, the DHS operator can obtain income from the increase of additional heat and electricity supply in the network (when heat is supplied from a cogeneration source). In this case, the annual gross income will be determined by the relation:

$$V_{brut.an} = Q_{an} \cdot T_{heat} + W_{an} \cdot T_{el}, \quad (6)$$

where:  $Q_{an}$  - the thermal energy quantity supplied to the new consumer;  $T_{heat}$  - the tariff in force for the heat supplied;  $W_{an}$  - the electricity quantity supplied to the network;  $T_{el}$  - the current tariff for the electricity supplied to the network.

The additional annual heat consumption shall be calculated by summing up the heat consumption for the space heating and DHW preparation during and outside of the heating season:

$$Q_{an} = Q_{heat.seas.} + Q_{hot\ season} = Q_{heat.seas.}^{heat} + Q_{heat.seas.}^{DHW} + Q_{hot\ seas.}^{DHW}; \quad (7)$$

where:  $Q_{heat.seas.}^{heat}$  - the thermal energy consumption for space heating during the heating season;  $Q_{heat.seas.}^{DHW}$  - the thermal energy consumption for the DHW preparation during the heating season;  $Q_{hot\ seas.}^{DHW}$  - the thermal energy consumption for the DHW preparation outside of the heating season.

The annual thermal energy consumption supplied to the new consumer for the space heating can be easily determined from the heating load, which depends on the rooms/buildings volume to be heated and the calculation temperatures of indoor and outdoor air [14]. The same, the thermal energy quantity supplied to a new consumer for the DHW preparation can be calculated by knowing the number of the DHW consumers and the specific consumption of DHW, using the methodologies set out in [15-16].

The annual electricity volume -  $W_{an}$  that will be produced additionally with the production of heat for the new consumer during the heating season -  $W_{heat.seas.}$ , and also outside of the heating season -  $W_{hot\ seas.}$ :

$$W_{an} = W_{heat.seas.} + W_{hot\ seas.}, \quad (8)$$

can be determined by applying regression analysis, the methodology of which will be presented in the next paragraph.

With the increase of heat and electricity supplies, there will be an increase in fuel consumption at the production source, which is part of the annual expenses, which in turn will be determined by the relation:

$$C_{an} = B_{an} \cdot T_{comb} + Amort_{an}; \quad (9)$$

where:  $B_{an}$  - additional annual fuel consumption;  $T_{comb}$  - the tariff in force for the consumed fuel for the production of heat and electricity;  $Amort_{an}$  - yearly depreciation of the equipment installed within the project (heat networks and IHP).

The additional annual fuel consumption in case of a new consumer connection will be determined with the relation:

$$B_{an} = B_{heat.seas.} + B_{hot\ seas.}; \quad (10)$$

where:  $B_{heat.seas.}$  and  $B_{hot\ seas.}$  represents the fuel consumption at the production source during the heating season and outside the heating season, respectively.

It should be noted that the correlation between fuel consumption and energy (heat and electricity) produced in cogeneration does not have the same value during a year due to the fact that during the heating season, a higher volume of thermal energy is produced and supplied - for space heating and DHW preparation, while outside of heating season a smaller

volume of thermal energy is produced only for the DHW preparation. Outside of the heating season, the overall cogeneration efficiency may decrease as thermal load decreases. Respectively, outside of the heating season, the correlation degree between the variables - natural gas consumption - heat and electricity supplied, may be lower than during the heating season. This hypothesis can be demonstrated by applying the regression analysis. Also, by using the regression method, the additional volume of natural gas can be estimated in a new consumer connection to the DHS. It is also recommended to determine the extra fuel consumption separately for each season whether the thermal energy is produced at different CHPs depending on the season.

The annual depreciation of the equipment installed in the project can be determined according to the linear depreciation method, using the relation:

$$Amort_{an} = \sum_{i=1}^n \frac{V_i}{D_i}; \quad (11)$$

where:  $V_i$  - the financial value of each mounted equipment;  $D_i$  - normal service life of the installed equipment;  $n$  - number of the installations.

### ***The research methodology***

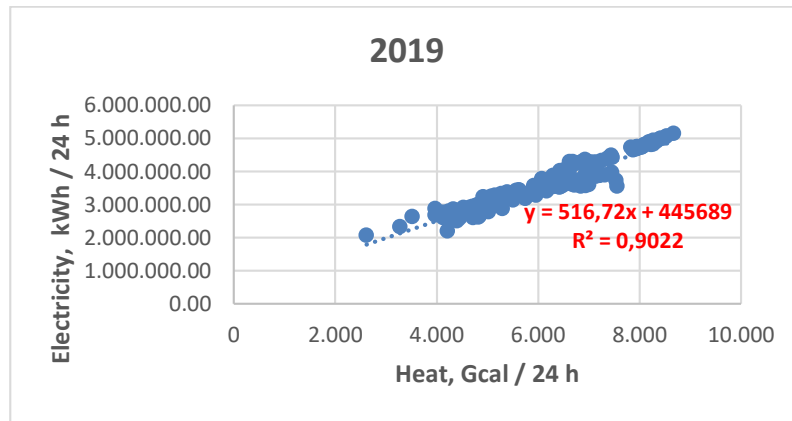
This article will present the method of applying linear regression in order to predict additional fuel consumption at CHP and the extra volume of electricity produced/supplied to the network in case of the new consumer connection to the DHS or previously disconnected consumer reconnection.

To draw the linear regression model related to the correlation between fuel consumption and additional supplies of heat and electricity produced in cogeneration, in case of new consumer connection to the DHS, as well as to assess the correlation between these two variables, the regression analysis with two variables will be applied (supplied heat and produced electricity), by using the daily data of the heat and electricity produced in cogeneration and supplied to the network, as well as of fuel consumption (natural gas) in a DHS in the Republic of Moldova during 2019.

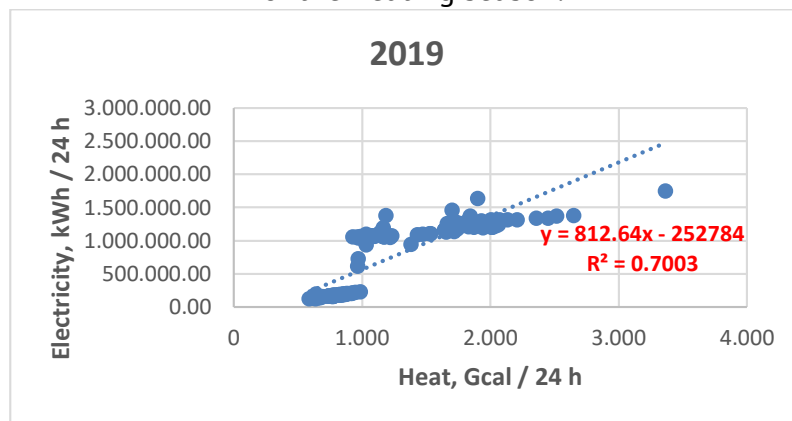
In the first stage, the hypothesis regarding the correlation between the resultant variables - fuel consumption and the variables considered influencing factors - the supplied heat and the produced electricity separately for the heating season and outside of the heating season should be verified. If high degrees of correlation is established between the variables, in the second stage, the regression models obtained to predict the additional fuel consumption and the additional electricity produced will be applied in case of the new consumer connection to the DHS via IHS.

### ***The regression analysis results: produced electricity - supplied heat***

The corresponding graphs for the heating season and outside of the heating season were constructed to verify the correlation between the additional electricity produced and the heat supplied to the network in case of the new consumer connection to the DHS. Based on the graphs, straight-line equations were generated and established the degrees of influence of the variables on the value  $R^2$  (Figures 4 and 5).  $R^2$  must obtain values higher than 0,5 to consider the heat supplied to the network as a determining factor for the produced electricity.



**Figure 2.** The regression analysis of electricity produced depending on the supplied heat for the heating season.



**Figure 3.** The regression analysis of electricity produced depending on the supplied heat, outside of the heating season.

When analyzing the graphs in Figures 2 and 3, it is observed that the graphical representation of the two variables is a straight line. Thus, it can be stated that there is a direct correlation between the electricity produced and the supplied heat, including the fact that  $R^2 > 0,5$ . There is a higher correlation degree during the heating season than outside the heating season, previously assumed in the paper.

**The methodology for the calculation of the additional electricity produced**

Thus, for the prediction of the additional electricity produced and supplied to the network, in case of the new consumer connection to the DHS, knowing the volume of thermal energy supplied to this new consumer, a straight-line equation can be used (Figures 2 and 3) and methodologies set out in Table 1 (for the heating season, lasting  $\tau_{heat.seas}$ ) and Table 2 (outside of the heating season, lasting  $\tau_{hot.seas} = 365 - \tau_{heat.seas}$ ).

Table 1

**Determination of production indicators at the CHP, during the heating season, as a result of the new consumer connection to the DHS**

Production indicators until the connection			Production indicators after connection	
Days of the season	Supplied heat	Produced electricity	Supplied heat	Produced electricity
1	$Q_{11}$	$W_{11}$	$Q_{12} = Q_{11} + (Q_{heat.seas}^{heat} + Q_{heat.seas}^{DHW} + Q_{loss}) / \tau_{heat.seas}$	$W_{12} = 516,72 \cdot Q_{12} + 445689$
2	$Q_{21}$	$W_{21}$	$Q_{22} = Q_{21} + (Q_{heat.seas}^{heat} + Q_{heat.seas}^{DHW} + Q_{loss}) / \tau_{heat.seas}$	$W_{22} = 516,72 \cdot Q_{22} + 445689$
3	$Q_{31}$	$W_{31}$	$Q_{32} = Q_{31} + (Q_{heat.seas}^{heat} + Q_{heat.seas}^{DHW} + Q_{loss}) / \tau_{heat.seas}$	$W_{22} = 516,72 \cdot Q_{22} + 445689$



Continuation Table 1

...	...	...	...	...
$\tau_{sez.inc}$	$Q_{\tau 1}$	$W_{\tau 1}$	$Q_{\tau 2} = Q_{\tau 1} + (Q_{heat.seas.}^{heat} + Q_{heat.seas.}^{DHW} + Q_{loss}) / \tau_{heat.seas.}$	$W_{\tau 2} = 516,72 \cdot Q_{\tau 2} + 445689$
<b>Total</b>	$\sum_{i=1}^{\tau_{heat.seas.}} Q_1$	$\sum_{i=1}^{\tau_{heat.seas.}} W_1$	$\sum_{i=1}^{\tau_{heat.seas.}} Q_2$	$\sum_{i=1}^{\tau_{heat.seas.}} W_2$

Table 2

Determination of production indicators at the CHP, outside of the heating season, as a result of the new consumer connection to the DHS

Production indicators until the connection			Production indicators after connection	
Days of the season	Supplied heat	Days of the season	Supplied heat	Days of the season
1	$Q_{11}$	$W_{11}$	$Q_{12} = Q_{11} + (Q_{hot.seas.}^{DHW} + Q_{loss}) / \tau_{hot.seas.}$	$W_{12} = 812,64 \cdot Q_{12} - 252784$
2	$Q_{21}$	$W_{21}$	$Q_{22} = Q_{21} + (Q_{hot.seas.}^{DHW} + Q_{loss}) / \tau_{hot.seas.}$	$W_{22} = 812,64 \cdot Q_{22} - 252784$
3	$Q_{31}$	$W_{31}$	$Q_{32} = Q_{31} + (Q_{hot.seas.}^{DHW} + Q_{loss}) / \tau_{hot.seas.}$	$W_{32} = 812,64 \cdot Q_{32} - 252784$
...	...	...	...	...
$\tau_{sez.cald}$	$Q_{\tau 1}$	$W_{\tau 1}$	$Q_{\tau 2} = Q_{\tau 1} + (Q_{hot.seas.}^{DHW} + Q_{loss}) / \tau_{hot.seas.}$	$W_{\tau 2} = 812,64 \cdot Q_{\tau 2} - 252784$
<b>Total</b>	$\sum_{i=1}^{\tau_{hot.seas.}} Q_1$	$\sum_{i=1}^{\tau_{hot.seas.}} W_1$	$\sum_{i=1}^{\tau_{hot.seas.}} Q_2$	$\sum_{i=1}^{\tau_{hot.seas.}} W_2$

In Table 1,  $Q_{loss}$  represents the distribution heat losses through the new route of the heating networks if the new consumer connection to the DHS requires to build the new thermal networks. Thus, the additional electricity produced and supplied to the network during the heating season, in case of the new consumer connection to the DHS, will be calculated with the relation:

$$W_{heat.seas.} = \sum_{i=1}^{\tau_{heat.seas.}} W_2 - \sum_{i=1}^{\tau_{heat.seas.}} W_1, \tag{12}$$

and the additional electricity produced and supplied to the network outside of the heating season, in case of the new consumer connection to the DHS, will be calculated with the relation:

$$W_{hot.seas.} = \sum_{i=1}^{\tau_{hot.seas.}} W_2 - \sum_{i=1}^{\tau_{hot.seas.}} W_1. \tag{13}$$

**The regression analysis results: fuel consumption - supplied heat and electricity**

To verify the correlation between fuel consumption and supplied heat and electricity to the network, the regression analysis with two variables will be applied, by applying the *Regression* feature in the *Data Analysis* package, from the *Microsoft Excel* tool. The daily values of fuel consumption are selected as a dependent variable and as independent variables - the thermal energy (variable 1) and electricity (variable 2) supplied to the network separately for the cool and warm seasons. The results generated by the program are shown in Figures 4 and 5.

## SUMMARY OUTPUT

<i>Regression Statistics</i>	
<b>Multiple R</b>	<b>0,99679384</b>
R <sup>2</sup>	0,99359796
Adjusted R <sup>2</sup>	0,993517431
Standard Error	21392,72487
Observations	162

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	1,12933E+13	5,64666E+12	12338,41704	4,0023E-175
Residual	159	72766139714	457648677,4		
Total	161	1,13661E+13			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95,0%</i>	<i>Upper 95,0%</i>
<b>Intercept</b>	<b>50193,70732</b>	9094,890582	5,51889073	0,0000001	32231,33287	68156,08178	32231,33287	68156,08178
<b>X Variable 1</b>	<b>89,88904024</b>	4,219549583	21,30299419	0,0000000	81,5554458	98,22263469	81,5554458	98,22263469
<b>X Variable 2</b>	<b>0,220656856</b>	0,007756297	28,44873691	0,0000000	0,205338199	0,235975514	0,205338199	0,235975514

**Figure 4.** The results of the data processing: fuel consumption - energy supplied to the network during the cool season, by the linear regression method.

## SUMMARY OUTPUT

<i>Regression Statistics</i>	
<b>Multiple R</b>	<b>0,991238681</b>
R <sup>2</sup>	0,982554122
Adjusted R <sup>2</sup>	0,982326071
Standard Error	24297,3477
Observations	156

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	2	5,08713E+12	2,54356E+12	4308,489946	3,0868E-135
Residual	153	90325249130	590361105,4		
Total	155	5,17746E+12			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>	<i>Lower 95,0%</i>	<i>Upper 95,0%</i>
<b>Intercept</b>	<b>37406,39821</b>	5144,886607	7,27059721	1,72472E-11	27242,21006	47570,58636	27242,21006	47570,58636
<b>X Variable 1</b>	<b>43,17719422</b>	6,751317019	6,39537354	1,84477E-09	29,8393577	56,51503074	29,8393577	56,51503074
<b>X Variable 2</b>	<b>0,315245273</b>	0,006952531	45,34252273	1,32746E-90	0,301509921	0,328980625	0,301509921	0,328980625

**Figure 5.** The results of the data processing: fuel consumption - energy supplied to the network during the warm season, by the linear regression method.

Analyzing the high values of the multiple correlation coefficients  $R = 0,996$  for the cool season and  $R = 0,991$  for the warm season, it results that there is a high intensity of the correlation between fuel consumption and all independent variables - heat and electricity supplied to the network during the 2019 year. The same is demonstrated by values greater than 0,05 obtained for *Significance F* and *P-Value*.

### ***The methodology for the calculation of the additional fuel consumption at the CHP***

For the prediction of additional fuel consumption at the CHP, in case of the new consumer connection to the DHS, knowing the additional volumes of the heat and electricity supplied to the network, the coefficients obtained as a result of the regression analysis (Figures 4 and 5) and the methodologies set out in Table 3 (for the heating season, lasting  $\tau_{heat.seas.}$ ) and Table 4 (outside of the season, lasting  $\tau_{hot.seas.} = 365 - \tau_{heat.seas.}$ ).

Table 3

**The fuel consumption determination at CHP, during the heating season, as a result of a new consumer connection to the DHS**

Production indicators after connection			
Days of the season	Heat supplied	Electricity produced	Natural gas consumption
1	$Q_{12}$	$W_{12}$	$B_{12} = 50193,707 + 89,889 \cdot Q_{12} + 0,220 \cdot W_{12}$
2	$Q_{22}$	$W_{22}$	$B_{22} = 50193,707 + 89,889 \cdot Q_{22} + 0,220 \cdot W_{22}$
3	$Q_{32}$	$W_{32}$	$B_{32} = 50193,707 + 89,889 \cdot Q_{32} + 0,220 \cdot W_{32}$
...	...	...	...
$\tau_{sez.inc}$	$Q_{\tau 2}$	$W_{\tau 2}$	$B_{\tau 2} = 50193,707 + 89,889 \cdot Q_{\tau 2} + 0,220 \cdot W_{\tau 2}$
Total	$\sum_{i=1}^{\tau_{heat.seas.}} Q_2$	$\sum_{i=1}^{\tau_{heat.seas.}} W_2$	$\sum_{i=1}^{\tau_{heat.seas.}} B_2$

Thus, the additional fuel consumption at the heat source during the heating season, in case of a new consumer connection to the DHS, will be calculated with the relation:

$$B_{heat.seas.} = \sum_{i=1}^{\tau_{heat.seas.}} B_2 - \sum_{i=1}^{\tau_{heat.seas.}} B_1, \tag{14}$$

where:  $\sum_{i=1}^{\tau_{heat.seas.}} B_1$  - fuel consumption at CHP during the 2020 heating season, before the connection of the new consumer.

Table 4

**Determination of the fuel consumption at CHP, outside of the heating season, as a result of a new consumer connection to the DHS**

Production indicators after connection			
Days of the season	Heat supplied	Electricity produced	Natural gas consumption
1	$Q_{12}$	$W_{12}$	$B_{12} = 37406,398 + 43,177 \cdot Q_{12} + 0,315 \cdot W_{12}$
2	$Q_{22}$	$W_{22}$	$B_{22} = 37406,398 + 43,177 \cdot Q_{22} + 0,315 \cdot W_{22}$
3	$Q_{32}$	$W_{32}$	$B_{32} = 37406,398 + 43,177 \cdot Q_{32} + 0,315 \cdot W_{32}$
...	...	...	...
$\tau_{sez.cald}$	$Q_{\tau 2}$	$W_{\tau 2}$	$B_{\tau 2} = 37406,398 + 43,177 \cdot Q_{\tau 2} + 0,315 \cdot W_{\tau 2}$
Total	$\sum_{i=1}^{\tau_{hot.seas.}} Q_2$	$\sum_{i=1}^{\tau_{hot.seas.}} W_2$	$\sum_{i=1}^{\tau_{hot.seas.}} B_2$

Thus, the additional fuel consumption at CHP outside of the heating season, in case of a new consumer connection to the DHS, will be calculated with the relation:

$$B_{hot.seas.} = \sum_{i=1}^{\tau_{hot.seas.}} B_2 - \sum_{i=1}^{\tau_{hot.seas.}} B_1, \tag{15}$$

where:  $\sum_{i=1}^{\tau_{hot.seas.}} B_1$  - fuel consumption at CHP during the 2019 warm season, before the connection of the new consumer.

## Conclusions

The regression analysis use, having as variables the thermal energy supplied to the DHS and the additional electricity produced in cogeneration at CHP, demonstrated a direct and linear correlation between these two variables. The same was shown for the correlation between fuel consumption and the electricity and heat produced in cogeneration at CHP.

Thus, it is recommended to use the regression analysis methods described in the article to predict the additional electricity produced, along with the heat supplied to the new heat consumer connected to any DHS in which these two forms of energy are produced simultaneously, as well as to predict additional fuel consumption in this case.

The obtained results can be used in the feasibility studies for projects of new consumers connection to the DHS via IHP by applying the method of economic evaluation of these types of projects presented in the article.

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## STRUCTURAL PARAMETERS OF CONCRETE CORROSION RESISTANCE

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**Abstract.** This article describes the problem of corrosion of concrete at the enterprises of the wine and fruit and vegetable industry in Moldova, the kind of organic acids that destroy concrete are considered. Such a specific type of chemical corrosion as leaching is also considered. The reaction of the influence of malic acid on concrete is reflected, as a result of which readily soluble calcium malic acid is formed. The structural parameter of corrosion resistance to chemical corrosion has been studied. The formula for the corrosion resistance of concrete is derived and explained. The structural parameter of resistance to chemical corrosion is investigated on various types of concrete. The formula for coefficient resistance of concrete to chemical corrosion is derived. Also, two dependencies are displayed: Dependence of the coefficient of resistance of concrete to chemical corrosion on the volume of cement stone; Dependence of the coefficient of concrete resistance to leaching corrosion on the structural parameter.

**Keywords:** *corrosion destruction of concrete, calcium hydroxide, coefficient of resistance, parameter of concrete corrosion resistance, volume of the modified cement stone, structural parameter of leaching corrosion, the porosity of the 1st and 2nd groups.*

**Abstract.** Acest articol descrie problema coroziunii betonului la întreprinderile din industria vinului, fructelor și legumelor din Moldova. Sunt luate în considerare, ce fel de acizi organici distrug betonul. Un astfel de tip specific de coroziune chimică precum levigarea este, de asemenea, luat în considerare. Se reflectă reacția influenței acidului malic asupra betonului, în urma căreia se formează acid malic de calciu ușor solubil. A fost studiat parametrul structural al rezistenței la coroziune la chimică. Este derivată și explicată formula pentru rezistența la coroziune a betonului. Parametrul structural de rezistență la coroziune chimică este investigat pe diferite tipuri de beton. Este derivată formula pentru coeficientul de rezistență al betonului la coroziune chimică. De asemenea, sunt afișate două dependențe: Dependența coeficientului de rezistență al betonului la coroziune chimică de volumul pietrei de ciment; Dependența coeficientului de rezistență a betonului la coroziune prin levigare de parametrul structural.

**Cuvinte cheie:** *distrugerea betonului la coroziune, hidroxid de calciu, coeficientul de rezistență, parametrul de rezistență la coroziune a betonului, volumul pietrei de ciment modificate, parametrul structural al coroziunii prin levigare, porozitatea grupelor 1 și 2.*

## Introduction

At the enterprises of the wine and fruit and vegetable industry in Moldova, a significant part of the reinforced concrete structures of buildings and structures, as well as technological equipment (floors, columns and walls, reinforced concrete bunkers for receiving fruit and vegetable raw materials, tanks for storing processed fruit and vegetable products, etc.) are practically in operation. under the constant influence of aggressive environments.

The destructive effect on concrete is exerted, first of all, by organic acids (lactic, malic, acetic, citric, tartaric) and others. These substances react with calcium hydroxide  $\text{Ca(OH)}_2$ , forming soluble calcium salts, which dissolve and pass into food products.

To a certain extent, the destruction of concrete also occurs under the influence of various microorganisms contained in the products of processing of fruits and vegetables.

In the problem of improving the quality of concrete at the enterprises of the fruit and vegetable industry, resistance to chemical corrosion will always occupy a special place, since it is this that has a decisive influence on the design service life of the structure.

The experience of the construction and operation of wine-making and fruit-growing enterprises in Moldova shows that even in an uncontaminated air-humid environment, prefabricated reinforced concrete structures can be damaged due to corrosion of the reinforcement. In the presence of acid gases (for example, in factories for the production of juices, wines, where anhydride is used), the damage to reinforced concrete is even more significant.

Such a specific type of chemical corrosion as leaching is also dangerous. Cases are known when concrete wear due to leaching reached 5-10 cm. Of great importance, in particular, is the provision of the required resistance to leaching for cooling towers used for cooling various kinds of technological equipment continuously washed with soft water.

At the same time, the organization of monitoring the resistance of concrete to chemical corrosion at factories and construction sites does not meet modern requirements. Often, the operations of monitoring corrosion resistance are reduced to approximate estimates based on data on the quality of raw materials and the composition of concrete.

Experimental assessment of the corrosion resistance of concrete in factories is practically not carried out. For example, in the construction laboratories of Moldova there is not a single installation for testing concrete for resistance to chemical corrosion.

The reason for this is the laboriousness and duration of standard methods for testing the resistance of concrete to chemical corrosion, which makes them ineffective under factory conditions. Practice has shown the need to develop methods for predicting and accelerating the assessment of corrosion resistance of various types of concretes used at the enterprises of wine and fruit and vegetable production.

Theoretical and technological prerequisites give reason to believe that all these conditions should be met by methods for assessing the corrosion resistance of concrete by the parameters of their structure.

## Features of the development of corrosion processes in wine and fruit and vegetable enterprises

During operation, concrete and reinforced concrete structures are exposed to various liquid, solid and gaseous aggressive media, which, according to the existing classification [1, 2], are conventionally combined into three groups: physical, physicochemical and chemical.

Physical corrosion of concrete occurs as a result of its alternating drying and wetting, which is accompanied by deformations of shrinkage and swelling of the material, deposition of soluble salts in the pores of the cement stone, alternating freezing and thawing, and other temperature effects.

Physicochemical corrosion of concrete occurs due to leaching of the constituents of the cement stone and as a result of osmotic and concentration phenomena.

Chemical corrosion of concrete is caused by the interaction of the constituent parts of the cement stone with acids, alkalis, salt solutions, various organic compounds, as well as all corrosive gases.

The most common types of processed fruit and vegetable products are canned vegetables (pH = 3.7 ... 4.4) and vegetable marinades (pH <3.7).

Another widespread ecological product is juices, which are characterized by ecological data containing acids and sugars.

Taking into account the pH value of these products, the content of organic acids and sugar in them, it follows that they cause, first of all, chemical corrosion of concrete.

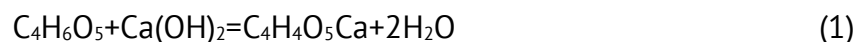
Organic acids contained in these products, upon contact with cement stone, interact primarily with  $\text{Ca}(\text{OH})_2$ , and then with hydrosilicates and calcium hydroaluminates to form readily soluble calcium salts that do not have astringent properties [3].

The rate of corrosion destruction of concrete largely depends on the structure of the formed layer of corrosion products, their degree of solubility, the access of an aggressive medium, its reactivity and the rate of its exchange at the concrete surface [4, 5].

The durability of reinforced concrete tanks operated in the food industry depends on the degree of aggressiveness of the environment in relation to concrete.

Food products differ in their chemical composition and, accordingly, their aggressiveness differs.

Fruit and berry juices are the most aggressive. Compared to grape juice, natural fruit and berry juices contain little sugar and a lot of acids, of which malic acid is the most aggressive [4]. The predominance of malic acid makes the juices more aggressive towards concrete, and upon contact with it, readily soluble malic acid calcium is formed [3] according to the following reaction "Eq.(1)".



The formed calcium malate does not possess astringent properties, which leads to the destruction of the inner surface of the tanks. Tartaric acid of grape juice [6, 7] reacts with  $\text{Ca}(\text{OH})_2$  of concrete cement stone, forming calcium tartrate. The formed calcium tartrate is slightly soluble and at the beginning of the operation of the tanks serves as a protective coating, but under the action of tartaric acid it turns into acidic calcium tartrate, which dissolves easily. Therefore, wines with a relatively high content of tartaric acid can dissolve the "protective layer" of calcium tartrate, and when the layer of tartar is 2-3 mm thick, harmful microflora begins to develop in it, which negatively affects the quality of the wine, and with a thickness of 4 - 5 mm on cracks form, and the wine, easily seeping, causes further corrosion of the concrete.

The destruction of the inner surface of the tanks degrades the quality of the wine, products of concrete corrosion and an unpleasant earthy aftertaste appear in it. The tartar is removed periodically with a hammer and scraper, which is quite difficult. In this case, the inner surface of the tanks becomes rough, which makes it difficult to rinse them. Lactic acid

contained in pickles and products, beer and wort [8], products of dairy and cheese factories [9], when interacting with  $\text{Ca}(\text{OH})_2$  of cement stone of concrete, forms lactate of lactic acid calcium. Other reactions of interaction of  $\text{Ca}(\text{OH})_2$  with organic acids contained in processed fruit and vegetable products proceed similarly.

Citric acid contained in juices and beer, upon interaction with  $\text{Ca}(\text{OH})_2$ , forms tricalcium citrate [8]. Under the action of acetic acid, which is used in the technological processes of canneries and contained in beer [8], concrete corrosion occurs in several stages with the formation of final products - silicic acid gel, calcium acetate and aluminum hydroxide gel.

Salts of these acids increase in volume during crystallization and destroy concrete [9, 10]. Sugar, carbon dioxide, alcohol, glycerin, which are part of the wort (pH = 5.5 ... 6.0) and beer (pH = 4.5 ... 5.6), form upon interaction with  $\text{Ca}(\text{OH})_2$  cement stone, readily soluble sugars, bicarbonates, alcoholate and calcium glycerate, which contribute to the destruction of building structures.

In confectionery factories, the most aggressive effect on building structures is provided by media containing glucosides. They penetrate deep into the concrete, causing corrosion of the reinforcement and destruction of concrete [11].

Acceleration of corrosion of reinforced concrete tanks when exposed to food environments is also caused by some salts, such as NaCl, for example, contained in fermented foods and pickles.

At meat processing and canning factories, NaCl solutions are used for cleaning premises. The same salt is sometimes sprinkled on floors. When concrete is impregnated with a NaCl solution, its physical corrosion occurs [12]. An external sign of this type of corrosion is the appearance of cracks in concrete and reinforced concrete structures.

In this case, the cause of corrosion is crystallization pressure, which reaches 0.27 MPa and is caused by the deposition of salt in the voids and pores of concrete during its periodic moistening and drying [3].

In addition, ions such as  $\text{Na}^+$ ,  $\text{Cl}^-$  increase the solubility of  $\text{Ca}(\text{OH})_2$ , which is the main regulator in the cement stone - water system. The amount of  $\text{Ca}(\text{OH})_2$  in Portland cement stone after one month of hardening is 9-11%, and after 3 months it reaches 15% of the cement mass [13].

Having the highest solubility,  $\text{Ca}(\text{OH})_2$  gradually leaches out when water acts on concrete, and free  $\text{Ca}(\text{OH})_2$  passes into the solution [1 - 3].

With the development of chemical corrosion in the structural elements of cement stone and other porous materials, mainly tensile stresses arise, as a result of which, under the action of external forces, its tensile strength decreases. Therefore, concrete with a lower tensile strength is less resistant to the development of chemical corrosion and its destruction occurs faster.

Thus, the destruction of cement stone and concrete under the influence of technological solutions of food production occurs mainly as a result of processes caused by chemical corrosion.

### **Structural parameter of concrete resistance to chemical corrosion (second type of corrosion)**

The solubility of cement hydration products in water and their chemical activity predetermine the possibility of a special type of corrosion - corrosion of the 2nd kind (according to V.M. Moskvina) [14]. This type of corrosion received its characteristic name due



to the fact that the most water-soluble and chemically active compound in cement stone is alkali - calcium hydroxide. The danger of corrosion of the 2nd kind in food enterprises has been known since the beginning of the last century [15]. Years of experience in the operation of various concrete structures have shown that this type of corrosion must be reckoned with. For example, there are known cases when the wear of concrete reached 5 ... 10 cm [16].

In essence, chemical corrosion has a certain specificity that must be taken into account when developing the corresponding structural parameter.

In particular, data on the solubility of cement stone components in water and on the kinetics of dissolution processes are very important.

The highest solubility and chemical activity, as already noted, among the compounds of cement stone is possessed by calcium hydroxide (portlandite). In addition, there is a lot of it in the cement stone - already after 3 months up to 15% of the cement mass [17]. The solubility of hydroxide in distilled water is quite high - 1.18 g / l in terms of CaO, in principle, the formation of supersaturated solutions with a CaO concentration of up to 1.9 g / l is possible. If conditions are created for the gradual decomposition of calcium hydroxide from the cement stone, then at the beginning free calcium hydroxide will pass into the solution, but when a significant part of it is removed, the hydrolysis of hydrosilicates and hydroaluminates of calcium will begin with the release of calcium hydroxide [14].

The least stable of the hydrosilicates is dicalcium hydrosilicate. At a hydroxide concentration of less than 0.05 g / l (pH = 11), hydrosilicates completely dissolve, and only  $\text{Si(OH)}_4$  gel remains in the solid phase.

The lower limit of the stable state of tricalcium hydroaluminate is the CaO content in the solution of 0.315 g / L [18]. All this information about the chemical stability of cement stone compounds is necessary to determine the structural parameter of resistance to leaching, in particular, when calculating the volume of "chemically modified" (according to F.M. Ivanov) during corrosion of cement stone "Figure 1".



**Figure 1.** Chemical corrosion of cement stone.

The process of destruction itself is also ambiguous. G. Hegerman [16], for example, divides it into three periods:

I period - decomposition of calcium hydroxide and decomposition of the smallest particles of clinker;

II period - coagulation of the formed gels  $\text{Al}(\text{OH})_3$  and  $(\text{OH})_4$  and partial adsorption of  $\text{Ca}(\text{OH})_2$ ;

III period - cessation of leaching of calcium oxide and enveloping the products of neoplasms with a film of silica gels.

According to Werner, the decomposition process is divided into 2 periods:

The first - is a short one, during which free calcium hydroxide rapidly decomposes;

The second - is a long period of hydrolysis of hydrosilicates and calcium hydroaluminates [14].

The general opinion of researchers is that the resistance of concrete to type 2 corrosion is determined by the density (impermeability) of the concrete and the content of unbound calcium hydroxide.

Naturally, its density plays an extremely important role in the resistance of concrete to chemical corrosion. The larger the surface area of contact between concrete and an aggressive medium and the filtration of water through concrete, the greater the rate of corrosion development.

But it would be wrong to assume that only density determines the resistance of concrete to chemical corrosion.

The rate and sequence of destruction of concrete under conditions of development of corrosion processes of the 2nd type is influenced by the mineral composition of cement clinker, the material composition of cement (content of mineral additives), as well as the structure of cement stone and concrete [4].

The resistance of concretes on various cements to chemical corrosion has been compared by many researchers [4, 14, 19]. The data of various authors on the leaching of lime from pozzolanic Portland cements convincingly prove the constructive role of active mineral additives. These additives not only change the chemical composition of the cement stone, but also reduce its permeability. It is proved that the corrosion process in concretes on slag Portland cements proceeds, all other things being equal, much slower than concretes on Portland cements. There is an increased durability of concretes based on alumina cements.

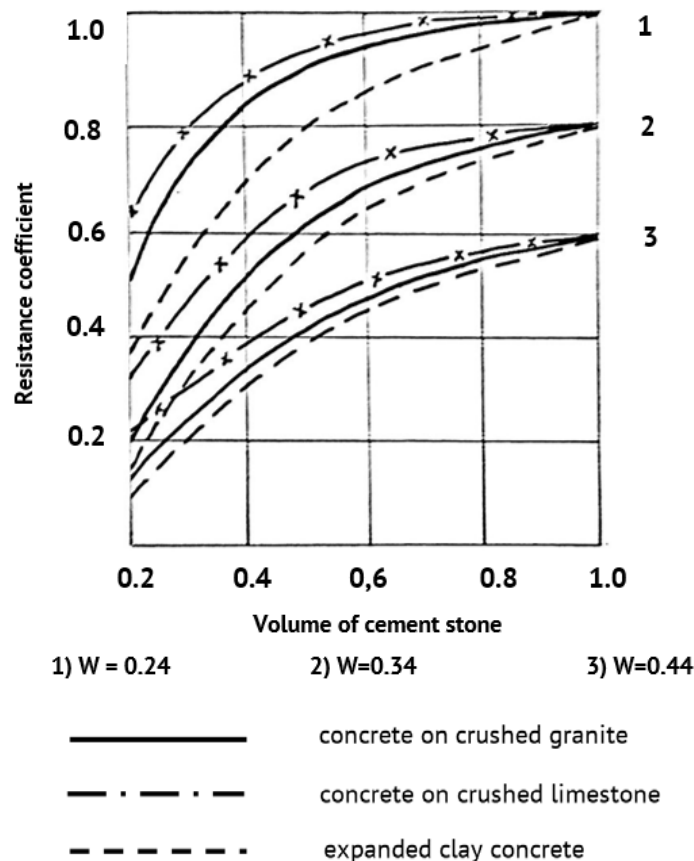
As for the studies of the relationship between the resistance of concrete to chemical corrosion and the characteristics of the structure, there are frankly few of them.

It has already been mentioned about the assessment of the role of the density of concrete, and hence their porosity, in the development of corrosion of the 2<sup>nd</sup> kind.

As an important negative structural factor, the introduced by F.M. Ivanov, an indicator of the development of corrosion is the degree of chemical degeneration of the cement stone. By the way, the available data show that after removing 10% of the lime (based on the original cement), the strength of concrete decreases rapidly, and its condition should be considered unstable. This critical value of the volume of the modified cement stone should be borne in mind when calculating the resistance values of concrete. should be borne in mind when calculating concrete resistance indicators.

Given the limited information on the effect of the characteristics of the structure of concrete on its chemical resistance, studies of this type of concrete corrosion are of particular interest.

Let us recall that the regularity of the increase in the resistance coefficient of concrete (according to V.V. Kind) with an increase in the volume of cement stone has been established "Figure 2".



**Figure 2.** Dependence of the coefficient of resistance of concrete to chemical corrosion on the volume of cement stone.

For all the seeming prosaicity, this is a very curious and remarkable fact, according to which the resistance of concrete does not depend on the content of calcium hydroxide in it. The unambiguous relationship between the resistance coefficient and the volume of communicating porosity has been confirmed. The important role in the development of corrosion processes of the contact zone between the cement stone and the aggregate has been revealed. The best resistance to this type of corrosion has been proven for carbonate concretes, which have a higher quality (in comparison with concretes on granite) contact zone.

The reduced resistance of expanded clay concrete is noted due to their high water absorption. It was found that "reserve" porosity does not play a significant role in the development of corrosion. Based on the above and taking into account the formula for the generalized structural parameter of resistance, the structural parameter of resistance to chemical corrosion can be expressed by the following relationship "Eq.(2)":

$$P_{cr} = (C - P_{total} - C_{mod}) / P_{1c} + P_{2c} \quad (2)$$

where  $P_{cr}$  is a parameter of concrete corrosion resistance;  $C$  – the volume of the cement stone;  $P_{total}$  – total porosity of concrete;  $P_{1c}$  and  $P_{2c}$  – respectively, the porosity of the 1st and 2nd groups, determined by the three-stage saturation method;  $C_{mod}$  – the volume of the modified

cement stone. From a physical point of view, this parameter is the volume of cement stone that can be destroyed at a given aggressiveness of the environment (such as an aggressive agent, time and operating conditions). It is determined by calculation, depending on the mineralogical composition of the cement, taking into account the peculiarities of the corrosion process. More often it is equal to the volume of calcium hydroxide contained in concrete.

In the denominator of the parameter, as destructive, are the pore volumes of the 1st and 2nd groups of cement stone and porous aggregate, since an aggressive medium enters the concrete through them. The volume of these pores largely determines the permeability of concrete. The composition of the pores of the 1st and 2nd groups entirely includes the porosity of the contact zone between the cement stone and the aggregate, which is the main way of filtering moisture through concrete.

According to the criterion dependence, it is assumed that  $(C - P_{total} - C_{mod})$ , the preserved dense frame of the cement stone, that is, the constructive volume, which determines the bearing capacity of concrete after corrosion.

Thus, the physical meaning of the structural parameter means the density of the placement of defects in the cement stone untouched by corrosion. It fully takes into account the fact that concretes on crushed granite are superior to expanded clay concretes in resistance to chemical corrosion, but inferior to concretes on limestone.

Analysis of the experimental data "Table 1" showed that the structural parameter satisfactorily describes the dependence of the resistance coefficient (according to V.V. Kind) on the characteristics of the structure.

Table 1

#### Determination of the structural parameter of resistance to chemical corrosion

N/o	Volume of cement stone	W / C cement stone	Porosity, proportion of concrete volume			The volume of the modified cement stone	Chemical corrosion resistance parameters	Resistance coefficient
			$p_1$	$p_2$	$P_{total}$			
1	2	3	4	5	6	7	8	9
<b>Concrete on crushed granite</b>								
1	0,2	0,24	0,042	0,085	0,125	0,029	0,36	0,36
2	0,3	0,24	0,043	0,087	0,169	0,044	0,67	0,68
3	0,4	0,24	0,044	0,088	0,174	0,055	1,29	0,81
4	0,5	0,24	0,045	0,091	0,179	0,075	1,81	0,90
5	0,6	0,24	0,047	0,093	0,185	0,090	2,32	0,95
6	0,2	0,34	0,060	0,091	0,150	0,024	0,17	0,20
7	0,3	0,34	0,065	0,120	0,228	0,038	0,19	0,37
8	0,4	0,34	0,073	0,146	0,267	0,050	0,38	0,51
9	0,5	0,34	0,081	0,160	0,290	0,063	0,61	0,60
10	0,6	0,34	0,087	0,173	0,310	0,076	0,82	0,68
11	0,2	0,44	0,080	0,101	0,175	0,021	0,05	0,13
12	0,3	0,44	0,089	0,131	0,250	0,032	0,10	0,24
13	0,4	0,44	0,094	0,188	0,334	0,043	0,11	0,34
14	0,5	0,44	0,100	0,220	0,374	0,055	0,22	0,41
15	0,6	0,44	0,120	0,240	0,415	0,066	0,33	0,48

Continuation Table 1

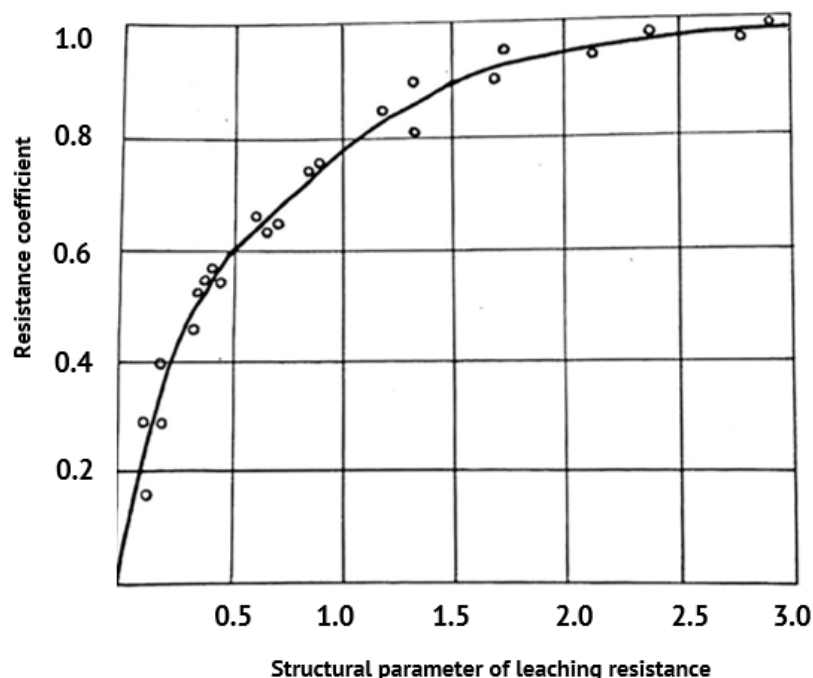
Concrete on crushed limestone								
16	0,3	0,24	0,047	0,093	0,138	0,044	0,84	0,75
17	0,4	0,24	0,050	0,097	0,154	0,055	1,30	0,87
18	0,5	0,24	0,051	0,098	0,164	0,075	1,85	0,94
19	0,6	0,24	0,052	0,100	0,174	0,090	2,41	0,97
20	0,2	0,34	0,063	0,102	0,147	0,024	0,18	0,30
21	0,3	0,34	0,072	0,135	0,209	0,038	0,26	0,46
22	0,4	0,34	0,080	0,160	0,242	0,050	0,47	0,57
23	0,5	0,34	0,083	0,165	0,271	0,063	0,67	0,66
24	0,6	0,34	0,090	0,175	0,293	0,076	0,89	0,73
25	0,2	0,44	0,085	0,138	0,169	0,021	0,09	0,25
26	0,3	0,44	0,094	0,178	0,237	0,032	0,11	0,33
27	0,3	0,24	0,047	0,093	0,138	0,044	0,84	0,75
28	0,4	0,44	0,103	0,205	0,326	0,043	0,12	0,40
29	0,5	0,44	0,111	0,232	0,368	0,055	0,23	0,47
30	0,6	0,44	0,125	0,257	0,408	0,066	0,34	0,52
Expanded clay concrete								
31	0,2	0,24	0,060	0,319	0,114	0,029	0,15	0,30
32	0,3	0,24	0,062	0,291	0,128	0,044	0,36	0,32
33	0,4	0,24	0,064	0,265	0,144	0,059	0,59	0,67
34	0,5	0,24	0,065	0,240	0,154	0,075	0,89	0,78
35	0,6	0,24	0,067	0,211	0,164	0,090	1,24	0,85
36	0,2	0,34	0,067	0,358	0,140	0,024	0,10	0,14
37	0,3	0,34	0,072	0,340	0,180	0,038	0,20	0,30
38	0,4	0,34	0,077	0,320	0,212	0,050	0,35	0,44
39	0,5	0,34	0,081	0,298	0,252	0,063	0,49	0,35
40	0,6	0,34	0,088	0,275	0,273	0,076	0,69	0,62
41	0,2	0,44	0,080	0,470	0,163	0,021	0,03	0,10
42	0,3	0,44	0,094	0,450	0,220	0,032	0,09	0,020
43	0,4	0,44	0,101	0,430	0,43	0,043	0,10	0,30
44	0,5	0,44	0,110	0,408	0,8	0,055	0,20	0,40
45	0,6	0,44	0,120	0,385	0,356	0,066	0,30	0,46

The analytical dependence of the relationship between the value of the structural parameter and the resistance index can be used to predict the resistance of concrete to chemical corrosion "Eq.(3)":

$$K_r = 0,61 \cdot P_{lc}^{0,57} \quad (3)$$

where  $K_r$  is the coefficient of resistance;  $P_{lc}$  - structural parameter of leaching corrosion.

According to the dependence "Figure 3", concretes with  $P_{lc}$  more than 2 ( $K_r > 0.9$ ) should be considered resistant. This is the value of the parameter for concretes based on pozzolanic and slag Portland cements with a sufficient, of course, density. Concretes based on alumina cement have high parameter values - more than 3. Concretes with  $P_{lc} < 2$  ( $K_r < 0.8$ ) should be considered unstable, the volume of hydroxide in them approaches the value of 0.1, which was noted as critical. However, it should be borne in mind that such parameters can also be present in concretes with active mineral additives, for example, at high W / C (water-cement ratio). Thus, the structural parameter can be used with sufficient efficiency to predict the resistance of any type of concrete to type 2 corrosion [20, 21].



**Figure 3.** Dependence of the coefficient of concrete resistance to leaching corrosion on the structural parameter.

Obviously, in the course of any processes of chemical corrosion of the 2nd type, the same factors are destructive - the volume of communicating porosity that filters an aggressive medium (porosity of the 1st and 2nd groups). Therefore, the denominator of the structural parameters of the resistance of concrete to chemical corrosion can be the same. The difference in the course of corrosion processes of the second type in the parameter is taken into account by the different volume of the degenerated cement stone - this volume depends on the specifics of one or another type of chemical corrosion. The more aggressive the environment, the less permeable the concrete, the lower the value of the parameter, the lower the corrosion resistance.

An experimental verification of the possibility of using the parameter to assess the resistance of concrete to chemical corrosion has been carried out. The largest selected series of concrete samples on various types of aggregates were tested for the resistance of concrete to the effects of tartaric, lactic and citric acids. A completely reliable relationship between the parameter and the resistance indicators has been confirmed.

### Conclusions

The destruction of cement stone and concrete under the influence of technological solutions of food production occurs mainly as a result of processes caused by chemical corrosion. In essence, chemical corrosion has a certain specificity that must be taken into account when developing an appropriate structural parameter. The durability of concrete does not depend on the content of calcium hydroxide in it. The unambiguous relationship between the resistance coefficient and the volume of communicating porosity has been confirmed. An important role in the development of corrosion processes of the contact zone between the cement stone and the aggregate has been revealed. The best resistance to this type of corrosion has been proven for carbonate concretes, which have a higher quality (in comparison with concretes on granite) contact zone.

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## A CASE STUDY ABOUT DEGRADATION OF THE BUILDINGS AND THEIR BUILDINGELEMENTS AS A RESULT OF CLIMATE CHANGE

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**Abstract.** The article deals with the problems of climate change and global warming, extreme climate phenomena, which present risk factors for the national economy, including construction. The causes that lead to the occurrence of the construction degradation phenomena are diverse and may be specific to improper exploitation, but also as a consequence of extraordinary natural phenomena or results from the humanity's interrelationship with the environment. The degradation of the constructions is manifested by the gradual loss of the physical and functional qualities that characterize the aptitude for their exploitation, the degradation process manifesting itself starting from the contact surfaces of the constructions with the environment. Urban planning and the design of adequate infrastructure play an important role in minimizing the impact of climate change and reducing the risk to the human environment. The undertaking's measures, which will consider the potential impact of climate change on buildings, will provide opportunities for new markets for climate change-resistant technologies, machinery, materials, and products.

**Keywords:** *climate variability, construction degradation, extreme climate phenomena, global warming, maintenance of buildings, project planning, risk management.*

**Rezumat.** În articol sunt tratate probleme legate de efectele schimbărilor climatice și a încălzirii globale, a fenomenelor climatice extreme care prezintă factori de risc pentru economia națională, inclusiv pentru domeniul construcțiilor. Cauzele care conduc la apariția fenomenelor de degradare a construcțiilor sunt diverse și pot fi specifice unei exploatare necorespunzătoare, dar și ca urmare a unor fenomene extraordinare naturale sau rezultate în urma interacțiunii dintre om și mediu. Degradarea construcțiilor se manifestă prin pierderea treptată a calităților fizice și funcționale ce caracterizează aptitudinea pentru exploatarea acestora, procesul de degradare manifestându-se începând de la suprafețele de contact ale construcțiilor cu mediul înconjurător. Planificarea urbană și proiectarea unei infrastructuri adecvate joacă un rol important în minimizarea impactului schimbărilor climatice și reducerea riscului asupra mediului antropoc. Întreprinderea măsurilor, care vor ține seama de impactul potențial al schimbărilor climatice asupra construcțiilor, vor oferi oportunități pentru piețe noi de tehnologii, utilaje, materiale și produse de construcții rezistente la efectele schimbărilor climatice. Cuvinte cheie: abordarea planificării, degradarea



construcțiilor, fenomene climatice extreme, încălzire globală, management al spațiului, minimizarea riscului, schimbări climatice.

**Cuvinte cheie:** *abordarea planificării, degradarea construcțiilor, fenomene climatice extreme, încălzire globală, management al spațiului, minimizarea riscului, schimbări climatice.*

### Introduction

The effects of climate change cause global warming, generating huge losses for the economy of the Republic of Moldova. These phenomena, in the form of strong wind gusts, floods, torrential rainfall, large hail, frost, excessive solar radiation that causes heat waves, low temperatures that in winter cause major damage to buildings, such as buildings, bridges, towers, power line poles, roads, dams, metal constructions, technological installations and equipment, historical and art monuments, etc., which induce serious risks to the health and safety of the population.

The complex action of these natural and technological environmental agents (chemical, physico-chemical, biological), as well as created errors by the existence of defects produced in the design and execution of construction works, considerably diminishing their exploitation and existence.

The causes that lead to the occurrence of construction degradation phenomena (see "Table 1") are diverse and may be specific to improper exploitation, as also according to extraordinary natural phenomena or resulting from the humanity's interrelationship with the environment [1].

The great climate variability of the last decades requires detailed and permanent research to consider the attested climate changes, both in making various applicable decisions and in the correct adaptation to these changes.

Knowledge to action of these climate phenomena is extremely important, to foresee in the future measures to minimize the consequences in different areas of the national economy.

Table 1

**Table 1 Physico-chemical degradation factors in constructions**

The risk factors	Nature factor	Time period occurrence	Probability of occurrence
Natural factors			
Excessive rainfall accompanied by hail, solar radiation	physics	of long continuance	continuous cycles
Humidity, temperature (variations)	physics	of long continuance	continuous cycles
The snow	physics	of long continuance	continuous cycles
Strong winds	physics	of long continuance	continuous cycles
Polluted air	physics	of long continuance	continuously

Continuation Table 1

Land movements (deformations, displacements) because of soil wetting	physics	of long continuance	continuously
Landslides	physics	Quick installation	rare
Factors resulting from the relationship man - construction - environment			
Pollution	chemical	of long continuance	continuously
Corrosive actions (aggregate alkali reaction, expansive cements)	corrosive	Medium	without frequency

Studies [2] demonstrate the extremely variable time and space of basic climate parameters, which may contribute to the careful selection of measures to mitigate the consequences of climate change on various activities, including the construction sector in Moldova. Therefore, it is important to consider the climate parameters of recent years because they leave their mark on the manifestation of significant thermal and rainfall extremes.

### Degradation of buildings on environmental actions

The constructions are executed to protect the users and their goods, to carry out specific activities. The term degradation, in the field of civil engineering, refers to any negative change in specific characteristics (physical, chemical, or mechanical) that may affect the strength, stability or durability of a constructed material, element or assembly [3].

Corrosion is one of the most common causes of damage in the industrial area, as well as one of the costliest. Corrosion is a phenomenon of gradual deterioration of materials, under the interaction with aggressive factors present in the atmosphere.

An important source of building degradation is water infiltration, which favors the appearance of wetlands. Their occurrence may be due to natural causes, due to heavy rainfall or due to mistakes in the stages of execution of a construction project.

Degradation of buildings is manifested by the loss over time of physical and functional characteristics, which diminish their ability to operate. This process of degradation is manifested, mainly at the contact surface of the buildings with the environment. In buildings, such manifestations occur by uneven discoloration of facades, by disintegration of plasters, by wetting and staining the surfaces of building elements, by the appearance of efflorescence on masonry and rust stains due to excessive moisture, rot on wooden elements, attack of anaerobic bacteria etc.

The main components of the atmosphere, which act corrosively on metallic elements are excessive humidity in the atmosphere, oxygen ( $O_2$ ) and carbon dioxide ( $CO_2$ ). In addition, other components can be added, depending on the types of atmospheres, for example sulfur dioxide ( $SO_2$ ) in the atmosphere of industrial and urban areas.

In addition to the above mentioned, another phenomenon of influence in the stage of exploitation of buildings is the natural degradation of materials, regardless of their type and characteristics or the performance of periodic maintenance and maintenance of buildings.

In the case of roads, with asphalt or cement concrete pavements, the defects are manifested by cracks, potholes, open joints, exfoliated surface etc., and on pavements made

of concrete slabs, by surface pinches, cracks, chipped edges, etc. In the case of bridges, the degradations are manifested by the erosion of the concrete at the joints, the rusting of the steel parts and elements, the rot and degradation of the wooden structures etc.

In the case of masonry, damage is manifested by the disintegration of plasters and exposed masonry systems, the reduction of the mechanical strength of masonry blocks (especially limestone masonry) and connecting mortars, by the disintegration of porous surfaces because of freezing cycles. Thawing, due to the phenomenon of dampness, due to the persistent moisture retained in the pores of the masonry, due to the surface efflorescence etc. As degradation progresses into the constructive components of the construction elements, over time the safety of the constructions may be affected by changing the relationships considered permissible between stresses and strengths.

The decrease in the characteristics of concrete and reinforced concrete elements and structures is due, first of all, to the destructive actions of environmental phenomena (major seismic actions to which the territory of the Republic of Moldova is exposed, corrosive atmospheric environment, rain and wind storms, strong gusts of wind, catastrophic floods, explosions accompanied by fires, lightning with electric discharges etc.), but also as a result of the inappropriate attitude of some specialists in the process of design and execution of construction works [4].

### **Concrete Degradation through corrosion**

The factors that influence the corrosion process of cement stone in concrete and its aggregates are physical, chemical, and biochemical.

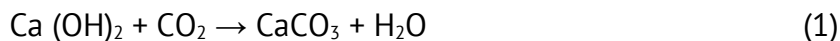
The temperature variation of the environment is one of the physical factors, which influences the corrosion of concrete constructions. The tensile loads, but also the destructive mechanical phenomena lead to the disintegration of the concrete, due to the temperature variations of the aggressive environment, generating contraction phenomena in the hydration process of the cement in the fresh concrete, to the variations of the level and movement of the aggressive liquid environment, which represent physical and chemical phenomena, which favor the corrosion process of constructions. The solubilization process, induced by aggressive agents of cement hydration products, especially  $\text{Ca(OH)}_2$ , is the decisive physical phenomenon in concrete corrosion.

Chemical compounds in nature, in the form of salts and alkalis have a destructive action on concrete [5], destroying it to the point of losing the ability to exploit buildings.

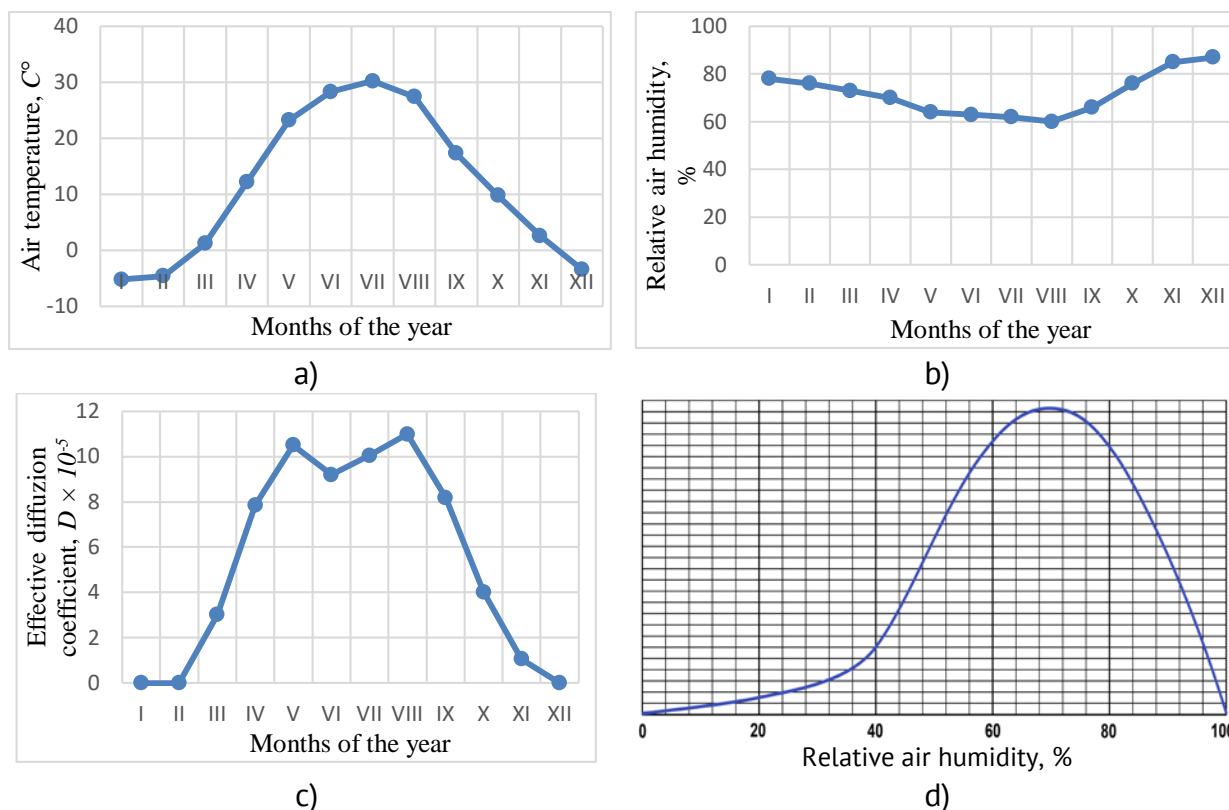
The most important chemical compounds with destructive action are: magnesium hydroxide ( $\text{Mg(OH)}_2$ ), which modifies the properties of cement; ammonium compounds, which decrease the mechanical strengths of limestone aggregates ( $\text{Ca(OH)}_2 + 2\text{NH}_4^+ = \text{Ca}^{2+} + 2\text{NH}_4\text{OH}$ ) and which subsequently exfoliate the concrete; sulphates, in particular 0,05 M ammonium sulphate ( $(\text{NH}_4)_2\text{SO}_4$ ), generate volume increases, leading to cracks in the concrete mass and detachment of its pieces; chlorinated ions lower the pH of concrete below 9, being a critical value that leads to corrosion of concrete reinforcement, with the effect of exfoliating it; the river water entails by washing the free lime from the cement generating a porous system in the concrete structures (at the bridge pillars); alkaline salts (5% NaOH, 5%  $\text{NH}_4\text{OH}$ ) crystallize into compounds, which disintegrate the concrete by expansion, leaving traces of efflorescence.

For example, carbon dioxide ( $\text{CO}_2$ ), present in the air of large cities (Chisinau, Balti, Cahul, Ungheni, Soroca etc.) in concentrations above the permissible limit, under the effect

of moisture (from 50 % to 80 %), by dissolution leads to the carbonation of concrete in cracks [6], forming insoluble calcium carbonate:



Thus, the problem of conducting experimental research on reinforced concrete elements was raised, regarding the variation of air temperature and humidity when calculating the carbonation depth of the concrete protection layer of the reinforcement, given the action of the corrosive atmospheric environment of Chisinau, where - considered the high temperatures of March-November of 2020 (Figure 1 a). During this time of year, the relative humidity of the air varied in the range from 60 % to 87 %, due to the annual amount of rainfall of 355-615 mm or 70 % - 105 % of the norm (Figure 1 b).



**Figure 1.** Influence of outside temperature and humidity on the effective diffusion coefficient  $D$  for the conditions of Chisinau municipality:

- a) average outside air temperature; b) relative air humidity; c) the effective diffusion coefficient  $D$ ; d) carbonation rate as a function of relative air humidity.

Because the effective diffusion coefficient  $D$  is a function of temperature and humidity, its value changed during the year (Figure 1 c), having a carbonation rate depending on the relative humidity of the air (Figure 1 d). For the calculations, the monthly average value of air temperature and humidity was used, as well as the corresponding values of the effective diffusion coefficient  $D$  of the concrete.

As it is shown in Figure 1, the value of the effective diffusion coefficient  $D$  changes significantly during the calendar year and these changes must be considered when calculating the carbonation depth of the concrete.

As a result of chemical reactions, calcium carbonate is formed from carbon dioxide, present in the atmosphere in excess, sealing the concrete structure, increasing its strength,

which leads to the neutralization of concrete [7], reducing its alkalinity. As a result of these reactions, concrete loses its protective properties for concrete reinforcement, generating its corrosion [8]. Heavy rain, which has a low concentration of minerals, washes away easily soluble carbon compounds, which is manifested by discoloration of the concrete surface, reducing its tensile strength and porosity, facilitating the carbonation process [9].

The effects of the chemical attack consist in the changes of the surfaces of the concrete elements [10], which are manifested by the disintegration of the cement stone, the increase of the cracks and joints, the detachment of pieces of concrete, exfoliation of the concrete protection layer of reinforcement, etc. In addition to the physical and chemical factors, the corrosion of the cement stone is also caused by biochemical factors, generated by microorganisms such as anaerobic bacteria, muscels, lichens, underwater algae, fungi etc.

Degradation and gradual destruction of concrete structures because of the corrosion effect depending on the mechanisms of its degradation, mentioned in [11] and [12], must be addressed in terms of durability, taking into account the geo- climate change of the Republic of Moldova.

### **Corrosion of reinforcement and metal elements**

The effects of extreme climate phenomena can also be manifested by corrosion of metal elements (atmospheric corrosion [13] and [14]), largely through surface defects or cracks in building elements [15]. For example, the periods of the year with heavy rains (spring and autumn), in combination with nitrogen dioxide ( $\text{NO}_2$ ) in the atmosphere, cause a corrosion rate of steel 4 times faster than in summer or winter. Oxygen ( $\text{O}_2$ ) in the atmosphere acts as a depolarizer, favoring the corrosion process ( $2\text{Fe} + \text{O}_2 = 2\text{FeO}$ ), having access to the metal surface, especially since the moisture film is thin. Carbon dioxide ( $\text{CO}_2$ ), with a high concentration in the atmosphere ( $\text{Fe} + \text{CO}_2 = \text{FeO} + \text{CO}$ ), dissolves easily in condensed water on the metal surface, causing rust stains.

The presence of other harmful compounds in the atmosphere, in addition to the three mentioned, leads to very wide changes in the corrosion rate [16].

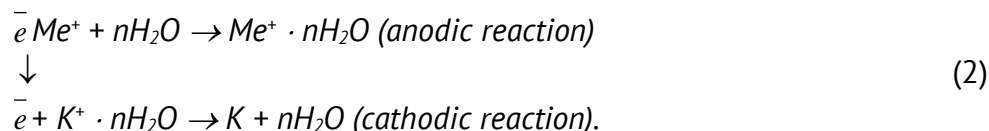
The process of corrosion in metals can develop in certain areas of the surface, this process is called "localized corrosion", and when the surface is evenly covered with rust – "uniform corrosion". Also, corrosion can selectively destroy the metal by cracking, at the grain boundary, called "intercrystalline corrosion", but also propagating through crystals – "transcrystalline corrosion", destruction caused by the direction of mechanical stresses of the metal element.

The destruction of metal elements of buildings as a result of electrochemical interaction (dissolving in air, containing moisture or water - called electrolyte) or chemical (formation of metal compounds with chemical agents with high aggressiveness) to the interaction with the external environment can cause significant damage. The damage caused to the national economy by metal corrosion is enormous, it can constitute at least 4 % of the country's annual income.

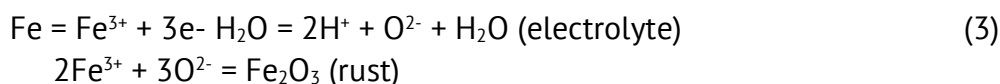
When local elements (micropyles) appear on the surface of the metal, because of galvanic cells, electrochemical corrosion causes changes in the metal (especially at high ambient temperatures), which is generally manifested by the loss of metal mass as due to reactions, which take place on the surface or in its cracks.

The electrochemical dissolution, which takes place on the surface of the reinforcement in the corrosion process [17], is in the form of two conjugate reactions:

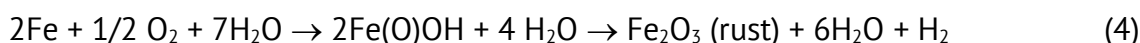
- *anodic reaction* - which consists in the passage of metal ion atoms from the crystal lattice in solution, accompanied by the release of electrons.
- *cathodic reaction* - which consists in the assimilation of these released electrons.



The electrolytic corrosion reaction of iron in the presence of water is:



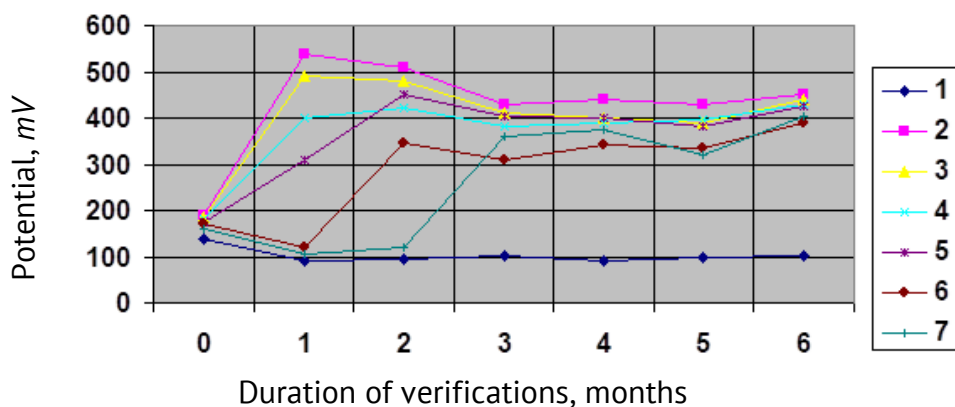
Usually, the chemical destruction of concrete reinforcements and metal surfaces occurs as a result of the action of gases ( $O_2$ ;  $SO_2$ ;  $H_2S$ ;  $HCl(g)$ ;  $CO$ ;  $CO_2$ ;  $H_2$ ), in an environment with high temperatures, but also because of their corrosion reaction in contact with water and vapors:



Biochemical corrosion is caused by the activity of microorganisms (mostly underwater in stagnant water), which use the metal as a nutrient chemical culture medium or eliminate highly corrosive products due to their metabolism. The products of the vital activity of microorganisms can also be aggressive to metal structures.

Decreasing the protective performance of concrete reinforcement, in terms of crack size, can endanger the safety of construction. Cracks with large openings diminish the rigidity of construction elements, increase their permeability, reduce the resistance to freeze-thaw cycles, and favor the appearance and development of the corrosion phenomenon of steel [18]. According to research, the process of destroying concrete, through the phenomenon of carbonation, attacks the crack walls and the damaged area of contact with the reinforcement. As a rule, the surface to which the carbonation spreads on the sides of the crack is proportional to the size of its opening.

By measuring with a potentiometer, was found that the electrochemical activity of the metal surface in undamaged concrete, in the wettest months of April-September, is characterized by a negative potential and considerable anodic polarization (Figure 2).

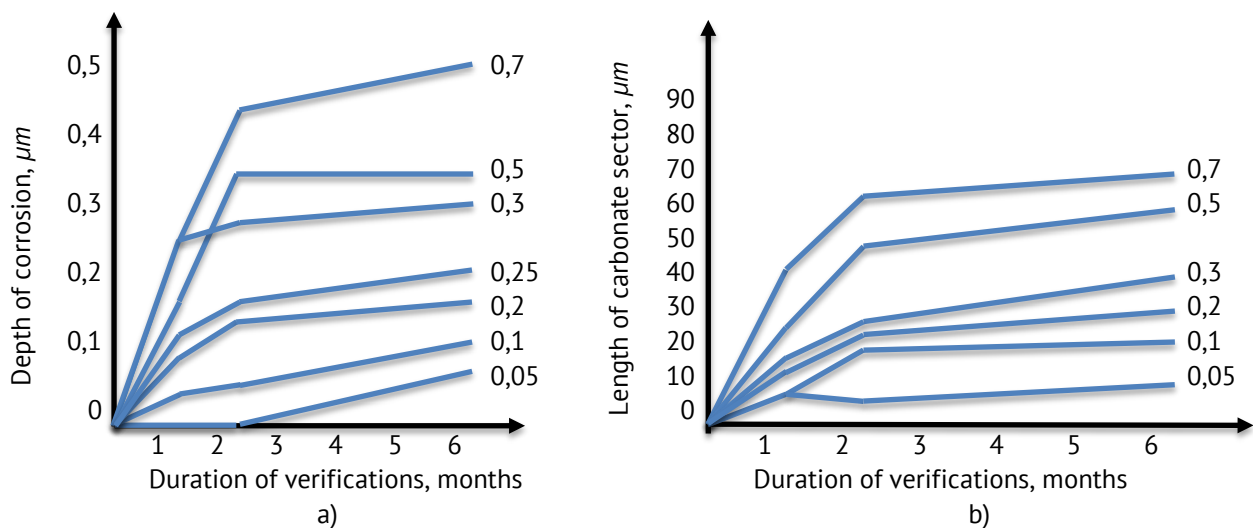


**Figure 2.** Change of steel potentials in cracks at periodic wetting with rainwater: 1 - without cracks; 2 ÷ 7 - the size of the cracks, accordingly: 0,7; 0,5; 0,4; 0,2; 0,1; 0,05 mm.

Electrochemical activity on the surface of the reinforcement, in the contact area with the crack, causes a local corrosion. Therefore, the existence of cracks in concrete, the corrosion resistance of the reinforcement, will depend on the specifics of the process and the kinetics of corrosion in different conditions of interaction of construction elements with the corrosive atmospheric environment.

As the variation of alternating wetting cycle's increases, within certain limits, the strength of the corrosion process also increases. Figure 3 shows that in the cracks with a size of 0.5 mm after the first month of verification, the average corrosion attack was 0.18  $\mu\text{m}$ , and the increase in the number of cycles - 0.36  $\mu\text{m}$ .

In constructions moistened with rainwater, the dangerous propagation of corrosion begins only in cracks with openings larger than 0.5 mm, and in cracks with openings smaller than 0.5 mm the speed of cathodic depolarization decreases, due to the phenomenon of self-cleavage of cracks concrete, which slows down the corrosion process.



**Figure 3.** Kinetics of reinforcement corrosion in concrete cracks, in depth (a) and along the surface of steel bars (b), at alternating wetting with rainwater. Next to the curves are indicated the opening sizes of the cracks, in mm.

The experimental results showed that the advanced corrosion of the concrete reinforcements was observed because of the penetration into the concrete of alkaline salts (5% NaOH, 5%  $\text{NH}_4\text{OH}$ ), which reach the surface of the reinforcements in the form of aerosols, contained in the absorbed atmospheric environment.

### Degradation of masonry materials

The degradation of masonry takes place, largely, due to mechanical and physico-chemical causes due to the action of climate factors, such as uneven subsidence of the land (sensitive to moisture); rain and snow; the combination of wind and rain; temperature variation; variation of relative humidity; air pollutants; soluble salts [19].

Moisture favors the degradation process of masonry, being a catalyst, which intensifies the degradation through soluble salts and other soluble substances in polluted air.

The capillary action in the porous materials of the masonry creates the suction effect, which produces the rising of water from the soil (which may contain salts in solution) and its retention, which leads to the risk of rapid degradation. In a building, wetlands can have variations in the percentage of humidity - about 10 % of the total floor area, and the costs of

maintaining these areas can be between 35 % and 50 % of the total costs involved in maintaining the entire building [20].

Soluble salts with different concentrations, circulating through the capillaries of the masonry, generate an osmotic pressure, influencing the spreading surface and the direction of water movement. Water vapor from the air, containing corrosive agents, penetrates the surface of the masonry, until it reaches a saturation equal to the humidity in the surrounding air.

Soluble salts, acting directly on the surface of the masonry or being absorbed by capillary suction, crystallizing destroy the masonry by disintegration. Mortar cements usually contain many minerals, which are soluble in solutions, such as water and weak acids.

The air from industrial areas, being polluted with high concentration acid gases, also contains solid particles, which gradually erode the surface of the masonry. Mortar and masonry blocks being porous materials, they absorb moisture from the air, which damages the mortar over time, the phenomenon being attributed to the complex interaction of constituent materials, environmental factors, and construction techniques. Usually, the mortar is destroyed due to phenomena such as erosion, disintegration, chipping, pickling.

Strong wind gusts accelerate all forms of degradation of masonry and mortar, caused by air pollution.

Thus, due to heavy rains, in combination with air pollutants, efflorescence's appearance on brick or concrete masonry surfaces, due to porous migrations of  $\text{Ca}^{2+}$  ions in the form of  $\text{Ca}(\text{OH})_2$  to the masonry surface, where in contact with  $\text{CO}_2$  in the atmosphere it forms calcium carbonate  $\text{CaCO}_3$ . Water infiltrations, both in brick, but especially in cement and sand-based mortars, entrain salts, but also other components, and after drying they are deposited on exterior or interior surfaces in the form of white spots (Figure 4).



**Figure 4.** Examples of efflorescence's on brick and concrete masonry surfaces.

### **Measures to be taken**

Climate change factors also include human activities, changing the environment and through this affecting people, nature and the national economy. The main problems today are the increasing concentration of carbon dioxide ( $\text{CO}_2$ ) in the atmosphere due to the burning of fossil fuels, corrosive aerosols in the atmosphere, as well as the cement industry, which accounts for about 5 % of  $\text{CO}_2$  emissions from industrial processes.

Climate change has a devastating impact on the branches and objects of the national economy, such as transport networks, construction and reconstruction of buildings and structures, urban and rural planning, increasingly affecting the health of the population.



Experts in the field believe that it is necessary to raise awareness of the problem of climate change and its consequences, improve the legal framework and technical regulations, involve the state in this process, develop a system to ensure meteorological and climate risks, create maps of vulnerability individual objects and territories of the country to climate change, development, and implementation of modern mechanisms for managing climate risks.

Important measures must be taken in this regard, such as:

- developing and promoting mechanisms for rapid prevention and intervention in urban and rural areas that demonstrate effectiveness in the event of disasters;
- elaboration of local plans for the reconstruction of the sewerage systems of each locality so that they can take over the excess rainwater in the built-up area, thus preventing floods;
- development of suitable paving systems, through which to infiltrate rainwater at the level of pedestrian traffic alleys, access roads, terraces, as well as for parking lots, storage areas etc.;
- increasing the areas of green plantations and providing water sources for their watering, in order to reduce the risk caused by excessive heat waves;
- revision of the National Annexes to Eurocode 1 [21] in order to update the climate values and the set of climate maps, in order to be used in the process of drafting normative documents related to the actions of climate factors on constructions and their elements, as well as on energy efficiency of buildings;
- integrated approach to project planning, design and management, within the project cycle management, in particular the characteristics related to the quality, technical and performance level of construction products [22], resistant to the actions of the environment, throughout the construction cycle life of buildings, taking into account the environment in which they will be operated;
- the development of construction regulations for green buildings, which ensure the design of construction objects related to the environment as a whole, where local climate conditions play an important role;
- elaboration of normative documents in constructions, which should offer constructive solutions for the improvement of the thermal insulation performances of the buildings, in order to make the energy consumption more efficient, according to the provisions [23];
- implementation of modern architectural concepts in order to achieve constructions, which offer a high degree of use of renewable energy sources, according to the provisions [23];
- production and promotion of materials, constructive solutions, which will cope with the potential effects of climate change;
- the use of durable anti-corrosion protections, their application in optimal conditions of the coating systems in extreme conditions, respecting the selection parameters in the coating and application, which are very important for obtaining a suitable result;
- the application of energy efficiency policy measures throughout the energy chain, the promotion of the use of energy efficient machinery and equipment, renewable energy sources, to final consumers, according to the provisions [24];

- elaboration and promotion of professional training programs for architects and designers, on the topic of ensuring the sustainability of constructions and buildings to the effects of climate change.

These measures will provide opportunities for new markets for climate change-resistant technologies, machinery, materials and construction products.

### Conclusions

The effects of climate change cause global warming, generating huge losses for the economy of the Republic of Moldova. To the effects of climate phenomena are added the emissions of a number of air pollutants, such as pollution by ozone, carbon dioxide, nitrogen dioxide and suspended dust, which accelerates the process of reducing the durability of buildings.

The studies carried out demonstrate the extremely variable time and space of the basic climate parameters, which will be able to contribute to the careful selection of measures to mitigate the consequences of climate change on various activities, including the construction sector.

There is a need to raise awareness of the issue of climate change and its consequences, improve the legal framework and technical regulations, involve the state in this process, develop a system to ensure meteorological and climate risks, create maps of vulnerability of individual objects and territories climate change, development, and implementation of modern climate risk management mechanisms.

The causes that lead to the occurrence appearance of the construction degradation phenomena are diverse and can be specific to improper exploitation, but also as a result of extraordinary natural phenomena or results from the humanity's interrelationship with the environment.

The undertaking actions, which will take into account the potential impact of climate change on buildings, will provide opportunities for new markets for construction technologies, machinery, materials and products that are resistant to the destructive actions of the environment.

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## PHYSICOCHEMICAL CHARACTERISTICS OF UNRIPE APPLES

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**Abstract.** Apple plays an important role in human health. The unripe apples, after physiological falls and the agricultural operation "regulation of the fruit load", are not used for food. The use of agricultural organic waste is a current problem. In the presented paper was approached the possibility of valorification on these unripe fruits to obtain natural products. Were studied the unripe apples of 4 varieties: Coredana, Golden Rezistent, Rewena and Reglindis. The fruits were harvested during development at 45<sup>th</sup>, 58<sup>th</sup>, 71<sup>st</sup>, 84<sup>th</sup> and 97<sup>th</sup> days after the full bloom. It was determined physico-chemical indices in fruits extracts. During the ripening of fruits, the diameter and mass increased continuously, the moisture content does not change significantly, but the pH values of the apple pulp increased non-essential. Dry matter content and total sugar increased considerably as the fruits were growing. There are unexpected increases in dry matter around the 84<sup>th</sup> day after the full bloom. The acidity decreased during the fruit development. Sensory evaluation was also effectuated. The results obtained provide informations regarding the optimal use of the unripe apple varieties researched in order to process and obtain different products (especially natural acidifiers).

**Keywords:** *unripe apples, total sugar content, acidity content, dry matter content, humidity, pH, sensory evaluation.*

**Rezumat:** Mărul joacă un rol important în sănătatea umană. Mere necoapte, obținute în urma căderilor fiziologice și a operațiunii agricole „reglarea încărcăturii de rod pe pom”, nu sunt valorificate în scop alimentar. Utilizarea deșeurilor organice agricole este o problemă actuală. În lucrarea prezentată este abordată posibilitatea valorificării acestor fructe pentru obținerea unor produse naturale. Au fost studiate fructele de mere imature de 4 soiuri: Coredana, Golden Rezistent, Rewena și Reglindis. Acestea au fost recoltate pe parcursul dezvoltării la 45, 58, 71, 84 și 97 zile de la fenofaza înflorirea deplină. În extractele acestora au fost determinați indicii fizico-chimici. În timpul dezvoltării fructelor, diametrul și masa au crescut continuu, conținutul de umiditate nu se schimbă esențial, iar valorile pH-ului pulpei de mere au crescut neesențial. Conținutul de substanțe uscate și zahărul total au crescut considerabil odată cu creșterea fructelor. Se observă o creștere bruscă a substanțelor uscate în jurul zilei a 84-a de la înflorirea deplină. Aciditatea a scăzut pe parcursul dezvoltării fructelor. Deasemenea a fost

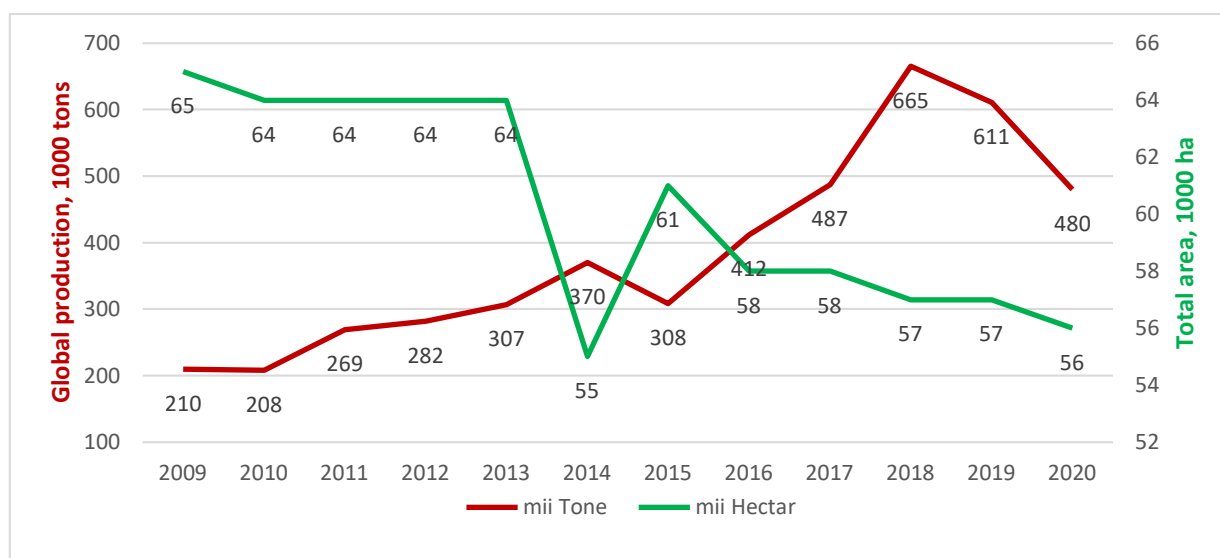
efectuată evaluarea organoleptică. Rezultatele obținute oferă informații cu privire la modul de utilizare optimă a soiurilor de mere imature cercetate în vederea prelucrării și obținerii diferitor alimente (în special acidifianți naturali).

**Cuvintele-cheie:** *mere imature, conținutul de acizi organici, conținutul de zahăr total, conținutul de substanțe uscate, umiditatea, pH, evaluare organoleptică.*

### Introduction

Apple is rich in organic acids, sugars, minerals and other nutrients, which play an important role in human health and one of the most important elements in the diet. These are the most demanded fruit by the Moldovan population and are eaten both fresh and processed. Due to their technological characteristics, they are raw material with a considerable share in the food industry. Thus, from a chemical point of view, they contain on average: 84 - 93% water, 0.3% ash, 8.30% reducing sugars, 1.60 - 4% sucrose, 0.90 - 1.70% cellulose, 0,50% pentosan, 0.40% lignin, 0.20% free acids, 0.60% combined acids, 0.4% pectin. In ash: potassium, sodium, silicon, calcium, phosphoric acid, iron, magnesium, bromine, sulfur, manganese, cobalt, tannin. In the peel and in the spine: galotanic acid [1, 2]. The core contains: ethers, acids - formic, acetic, capronic, acetaldehyde, geraniol. Regardless of the variety we choose, apples have in common most of the nutrients. What differs, to a greater or lesser extent, is the sugar content, up to 16% in the case of sweeter apples [1, 3].

In the Republic of Moldova, apples are the third highest value product in the agricultural sector in terms of revenue, being a strategic product for the northern part of the republic, where the largest plantations are located. The total area of orchards in our country reaches about 57 thousand ha, being cultivated about 40 varieties of apples, and apple production is estimated at about 611 thousand tons per year (Figure 1) [4].



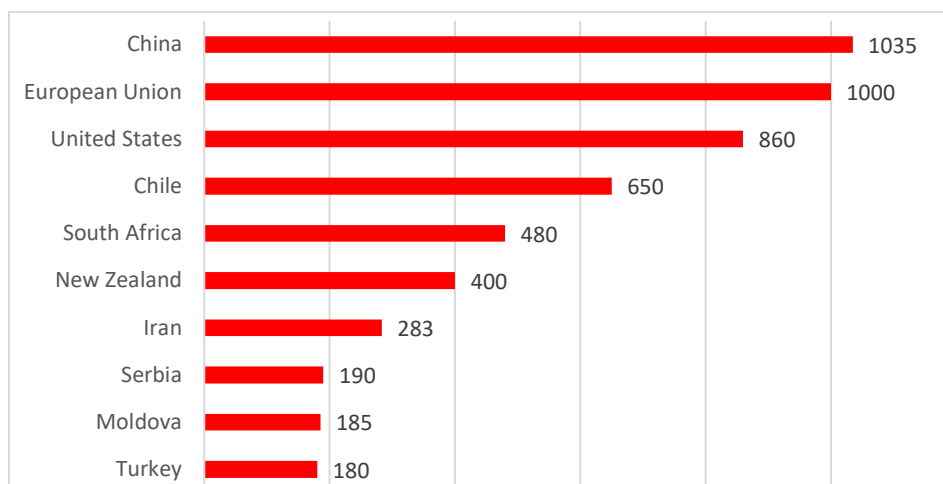
**Figure 1.** Evolution of apple plantations and harvest in the Republic of Moldova (years 2009-2019).

Source: taken from [4], processed by the author.

The sudden decrease of the plantation area in 2014 is due to the fact that the classic orchards were replaced with intensive ones and later with superintensive ones. The dry years leave a drastic mark on agriculture, affecting both the global production of apples and the

trees in the orchards. One of these years was 2020 with the global production of 480 thousand tons and the total area of plantations 56 thousand hectares.

According to statistical data elaborated by [Statista.com](https://www.statista.com) [5], the Republic of Moldova ranks 9<sup>th</sup> in the world by the volume of apples exported (Figure 2).



**Figure 2.** World leading countries in apple exports in the 2019/2020 marketing season, by volume exported in 1000 tons.

Source: taken from [5], processed by the author.

At the early phase of ripening apples, after physiological falls, the agricultural operation "regulation of the fruit load" takes place, after which about 25-30% of the expected fruit is removed (especially in years with insufficient soil moisture) [3]. The significant amount of unripe fruit is not used for food, but is transformed into green mass as a fertilizer [6] or simply left on the ground as waste. Apple waste, following anaerobic fermentation, leads to harmful emissions, worsening soil and air quality, emitting unpleasant odors.

At the same time, not enough acidifiers of natural origin are known in the food industry. Monoacids of chemical / biochemical origin are mostly used [7, 8].

Significant volumes of apples in the early ripening phase, which are obtained by regulating the load of the harvest, as well as the need for natural acidifiers for use in the food industry, requires as a basic task the valorification of these apples and obtaining products with significant organic acids native and other valuable nutrients [9, 10].

The aim of this study was to evaluate the physicochemical indices in unripe apples to provide information on the optimal use of studied unripe apple varieties in order to process and obtain different foods (especially natural acidifiers).

## Materials and methods

### Biological material

Raw materials for the study served unripe apples, in the early ripening phase, of 4 varieties: Coredana, Golden Rezistent, Rewena și Reglindis. These were picked between June 5 and July 24, 2019 from the experimental lots of the Scientific-Practical Institute of Horticulture and Food Technologies, Chisinau, Republic of Moldova. The fruits were harvested during development at 45<sup>th</sup>, 58<sup>th</sup>, 71<sup>st</sup>, 84<sup>th</sup> and 97<sup>th</sup> days after full bloom.

It was obtained extract from harvested apples by crushing and pressing. The yields of apple juices ranged from 30% to 50%.

### Determination of the quality indices of the unripe apples and them extracts

The diameter of the samples of unripe apples was measured using the callipers. The mass of the samples was determined by using electronic balance. The moisture content was determined by drying in the oven at  $103\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$  for 3 hours. The experiment was repeated until the constant mass has been achieved. The samples were cooled in the desiccator for one hour and weighed at the analytical balance [11].

To prepare the extracts, the washed apples were passed through a Slow screw extractor (Hotpoint, Ariston, Indesit Company). The juice obtained was centrifuged at  $5000\text{ rot} \times \text{min}^{-1}$  for 15 min. The filtration was then carried out through a cardboard filter with a diameter of  $0,45\text{ }\mu\text{m}$  of the holes. The collected filtrate served as a sample used to determine the titratable acidity, total sugar content, total soluble solids (dry counter), pH and sensory analysis. The clear juice was transferred to sealed bottles and stored at  $-20^{\circ}\text{C}$  until the analysis.

Content of dry matters (total soluble solids) was determined by electronic pocket refractometer ATAGO PAL-3 (Japan). The titratable acidity, content of total sugar and pH were determined using the methods described in ISO 750:1998 [12], by G. Bertrand and ISO 1842:1991 [13], respectively.

Standard ISO 6658: 2017 [14] was followed when performing the sensory analysis of the unripe apple extracts. Appearance, color, odor, taste, and overall acceptability were assessed using the 5-point system by an expert panel of eight trained food technologists. The panelists were between 35 and 75 years old. The 5-point assessment system includes the following scores: 5 – very good; 4 – good; 3 – satisfactory; 2 – poor; 1 – bad and 0 – very bad.

#### Statistical analysis

Variance analysis of the results was carried out by least square method with application of Microsoft Office Excel program. All analyses were performed in triplicate, with a maximum error of less than 5%. Results obtained were expressed as average  $\pm$  SD.

#### General description of the apples variety used include:

COREDANA – variety obtained at Pomiculture Research Institute in the Republic of Moldova. The tree has a small to medium growth force, with a flattened spherical crown. It bears fruit early, the flowering season is medium. Trees are not demanding of the soil, they have high winter hardiness, medium at drought and heat resistance. The variety also has genetic resistance to scab and medium resistance to powdery mildew. The fruit is large in size with a mass of 170-250 g, spherical shape, sometimes flattened. The covering color is red with streaks. The flesh is cream-white, fine, juicy, crunchy, with a sweet-sour taste. Harvest period: late August or early September. Productivity is 28-35 t/ha. Apples are resistant to handling and transport. The fruits can be stored 120-130 days. The variety is approved for all fruit-growing areas of the country [1, 3].

GOLDEN REZISTENT – variety obtained in SUA. The tree has a medium growth force, with a large-pyramidal and dense crown. It bears fruit early, the flowering season is medium. Trees are not demanding of the soil, they have high winter hardiness, medium resistance to powdery mildew and scab. Apple is medium to large in size, with a mass of 150-160 g. It has a conical-oblong to conical-truncated shape and a smooth surface. The covering color is yellow, but sun-exposed fruits may be covered with an orange blush. Harvest period: the 3<sup>rd</sup> decade of September - early October. Productivity is 30-40 t/ha. The fruits can be stored 180-210 days and are eaten mostly fresh. The variety is authorized for all areas of the republic [1, 3].



REGLINDIS – variety obtained in Germany. The tree has a medium to weak vigor, with a globular crown. It bears fruit early, the flowering season is medium. The trees are demanding to the soil, have medium winter hardiness. It has genetic resistance to scab and high resistance to powdery mildew. The fruit is of medium to large size, a mass of 170-200 g, with a globular or conical-globular shape. The covering color is red with streaks and occupies about 75% of the surface of the fruit. The flesh is fine, crunchy, white-cream, juicy, with a very good taste. Harvest period: the 2<sup>nd</sup> decade of September. Productivity is 30-35 t/ha. Apples are resistant to handling and transport. The fruits can be stored 90-115 days and are eaten mostly fresh [1, 3].

REWENA – new resistant variety obtained in Germany. It is considered one of the best varieties of apples in the world. The tree has a medium vigor, with a globular crown. It bears fruit early, the flowering season is medium. The trees are demanding to the soil, have high winter hardiness. It has stable scab resistance and high resistance to powdery mildew. The fruit is of medium to large size, a mass of 160-230 g, with a globular or conical-globular shape. The covering color is yellow with a light red blush that occupies about 70-90% of the fruit's surface. The flesh is fine, crunchy, white-cream, juicy and fragrant; with a sweet-sour taste. Harvest period: the 3<sup>rd</sup> decade of September - early October. Productivity is 30-35 t/ha. The fruits can be stored 90-115 days and are eaten mostly fresh [1, 3].



a)



b)



c)



d)

**Figure 3.** Image of apple fruits of the varieties Coredana (a), Golden Delicios (b), Reglindis (c), Rewena (d).

Source: taken from [1, 3].



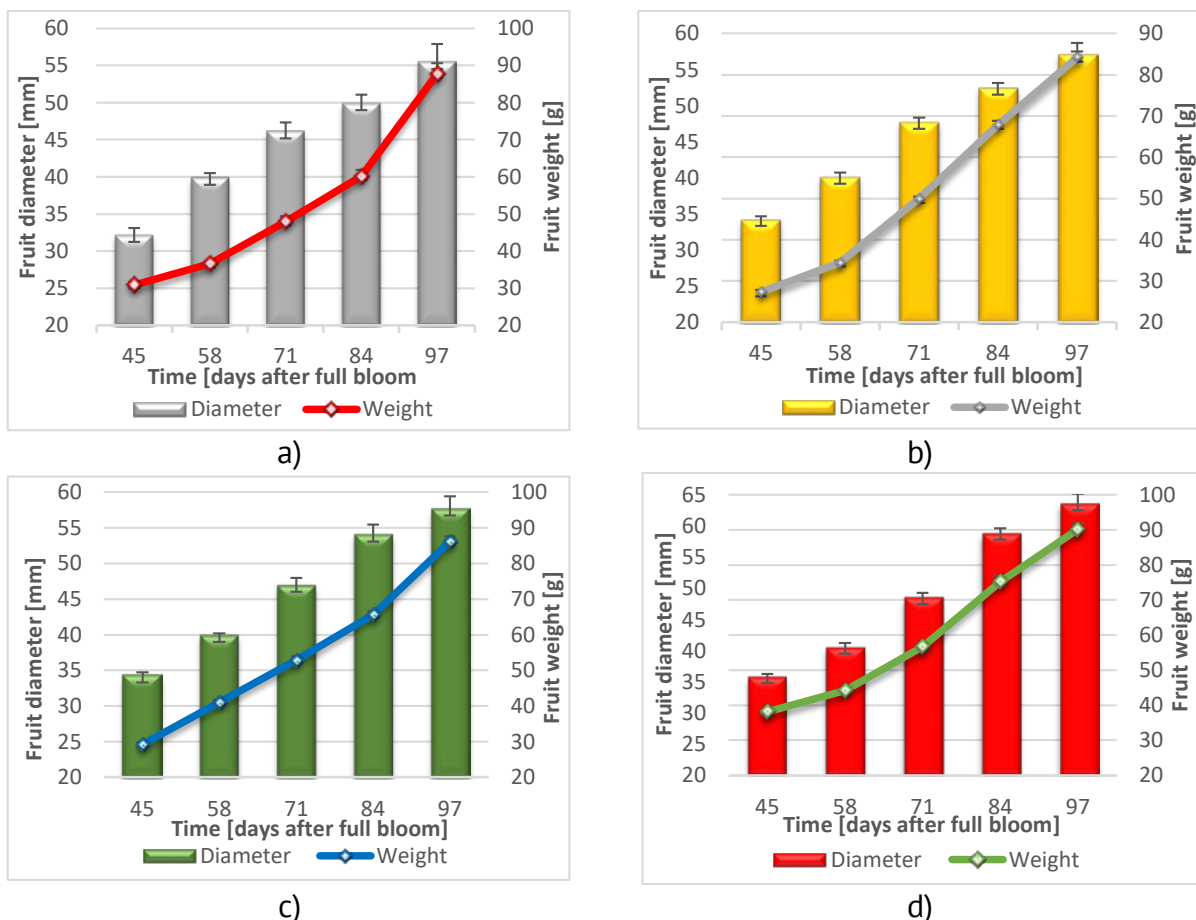
## Results and discussions

Between June 1 and July 24, 2019, unripe apples and their extracts were analyzed. Subsequently, samples of acidifiers were obtained from these apples in laboratory conditions. As a raw materials were used unripe apples, in the early ripening phase, of 4 varieties: Coredana, Golden Rezistent, Rewena și Reglindis.

As expected, the diameter and mass of the fruit during growth increased continuously for all the apple varieties analyzed [15, 16]. During the ripening process of apple fruits, various physiological changes take place (the process of photosynthesis).

Fruit development has 2 phases. The first stage starts from with blooming and lasts about 35 days, during which the exponential cell division takes place (the first 7 days) and the increase of the fruit mass due to the division and expansion of the cells (from the 7<sup>th</sup> to about the 35<sup>th</sup> day) [17]. The second phase of growth begins before the end of cell division and lasts until the fruits are harvested. Finally, growth for the rest of the season occurs mainly only by expanding the cells. During this period the fruit adds a similar amount of weight each day [16, 17].

The dynamics of the mass and diameter of the studied unripe apple fruits are presented in figure 4.



**Figure 4.** Dynamics of mass and diameter during the development of apple fruits of the varieties Coredana (a), Golden Delicios (b), Reglindis (c), Rewena (d).

Source: authored.

A preventive analysis of unripe apples in order to obtaining natural acidifiers was effectuate in 2016 [18]. That study has shown that unripe apple fruit is a source of valuable nutrients and native organic acids.

In this research the physico-chemical indices of apples and their extracts were studied at 45<sup>th</sup>, 58<sup>th</sup>, 71<sup>st</sup>, 84<sup>th</sup> and 97<sup>th</sup> days after the full bloom phenophase. That are presented in Table 1.

Table 1

**Physico-chemical indices of fruits of four apple varieties and extracts from these during their development (average  $\pm$  SD).**

Variety	Days AFB*	Moisture, %	Acidity**, %	Dry metter, (°Brix)	Total sugar, %	pH
Coredana	45	85,30 $\pm$ 0,95	1,83 $\pm$ 0,023	6,5 $\pm$ 0,01	3,87 $\pm$ 0,04	3,02 $\pm$ 0,021
	58	86,45 $\pm$ 0,83	1,75 $\pm$ 0,017	7,7 $\pm$ 0,02	5,20 $\pm$ 0,02	3,18 $\pm$ 0,002
	71	84,91 $\pm$ 0,70	1,60 $\pm$ 0,005	8,7 $\pm$ 0,01	6,33 $\pm$ 0,03	3,09 $\pm$ 0,003
	84	85,30 $\pm$ 0,72	1,54 $\pm$ 0,003	10,8 $\pm$ 0,00	9,08 $\pm$ 0,01	3,06 $\pm$ 0,008
	97	83,60 $\pm$ 0,24	1,20 $\pm$ 0,004	12,8 $\pm$ 0,01	11,18 $\pm$ 0,01	3,13 $\pm$ 0,001
Golden Rezistent	45	87,23 $\pm$ 0,53	2,20 $\pm$ 0,000	7,6 $\pm$ 0,01	4,65 $\pm$ 0,01	2,78 $\pm$ 0,003
	58	86,67 $\pm$ 0,07	2,09 $\pm$ 0,013	8,1 $\pm$ 0,02	5,21 $\pm$ 0,02	2,90 $\pm$ 0,004
	71	86,29 $\pm$ 0,23	1,82 $\pm$ 0,014	9,2 $\pm$ 0,01	7,13 $\pm$ 0,01	2,95 $\pm$ 0,001
	84	87,82 $\pm$ 0,02	1,77 $\pm$ 0,002	11,0 $\pm$ 0,01	8,73 $\pm$ 0,04	3,03 $\pm$ 0,001
	97	86,51 $\pm$ 0,32	1,50 $\pm$ 0,003	12,7 $\pm$ 0,00	10,30 $\pm$ 0,05	3,12 $\pm$ 0,000
Reglindis	45	84,60 $\pm$ 0,08	2,60 $\pm$ 0,012	6,3 $\pm$ 0,00	3,73 $\pm$ 0,03	3,02 $\pm$ 0,007
	58	83,20 $\pm$ 0,73	2,40 $\pm$ 0,007	7,6 $\pm$ 0,14	5,26 $\pm$ 0,04	3,16 $\pm$ 0,004
	71	84,30 $\pm$ 0,91	2,35 $\pm$ 0,012	8,4 $\pm$ 0,05	5,28 $\pm$ 0,02	3,00 $\pm$ 0,003
	84	84,50 $\pm$ 0,72	2,07 $\pm$ 0,006	10,4 $\pm$ 0,02	7,33 $\pm$ 0,02	3,27 $\pm$ 0,002
	97	83,90 $\pm$ 0,09	1,90 $\pm$ 0,018	11,9 $\pm$ 0,01	9,28 $\pm$ 0,01	3,45 $\pm$ 0,003
Rewena	45	86,70 $\pm$ 0,07	2,95 $\pm$ 0,012	6,7 $\pm$ 0,03	3,45 $\pm$ 0,08	2,20 $\pm$ 0,001
	58	86,30 $\pm$ 0,20	2,87 $\pm$ 0,007	7,8 $\pm$ 0,01	4,53 $\pm$ 0,01	2,43 $\pm$ 0,002
	71	87,05 $\pm$ 0,40	2,75 $\pm$ 0,001	8,3 $\pm$ 0,03	5,37 $\pm$ 0,02	2,70 $\pm$ 0,000
	84	86,90 $\pm$ 0,08	2,60 $\pm$ 0,001	10,5 $\pm$ 0,00	7,11 $\pm$ 0,05	2,77 $\pm$ 0,021
	97	86,50 $\pm$ 0,07	2,24 $\pm$ 0,002	12,0 $\pm$ 0,01	9,68 $\pm$ 0,04	2,94 $\pm$ 0,020

\* Days AFB – days after the full bloom

\*\* Titratable acidity, expressed in malic acid

During the growth and development of apple fruits, the moisture content does not change significantly, the values being between 83.20% and 87.82% for all 4 varieties studied.

The dry matter content increased considerably with the growth and development of the apple fruit, with values between 6.5°Brix and 12.8°Brix for the Coredana variety, between 7.6°Brix and 12.7°Brix for the Golden Resistant variety, between 6.3°Brix and 11.9°Brix for the Reglindis variety and between 6.7°Brix and 12.0°Brix for the Rewena variety. The highest values of this index were recorded for the Coredana and Golden Rezistent varieties, followed by the Rewena and Reglindis varieties. There are unexpected increases in dry matter around the 84<sup>th</sup> day after the full bloom, followed by a slow increase.

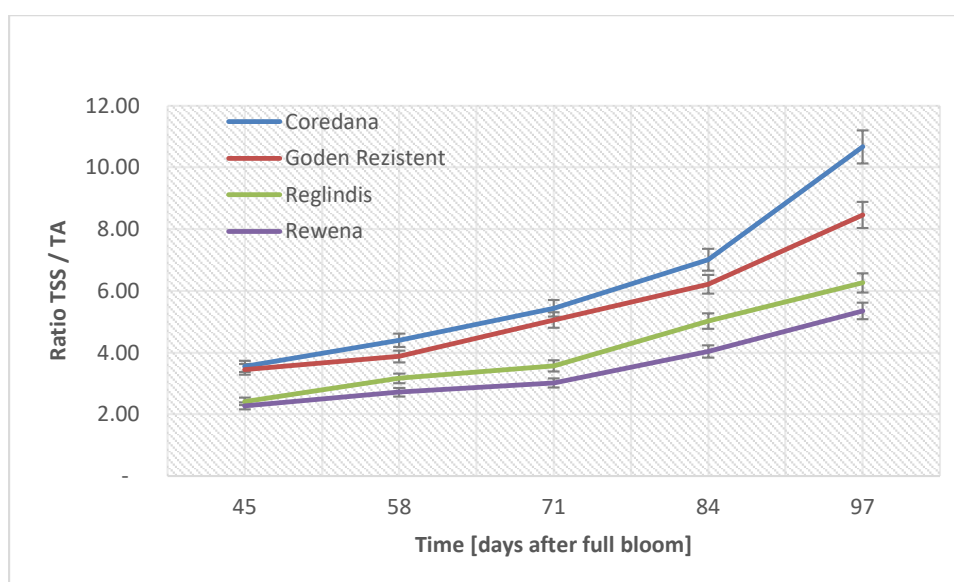
The total amount of carbohydrates increases significantly during fruit development, registering values between 3.87% and 11.18% for the Coredana variety, between 4.65% and 10.3% for the Golden Resistant variety, between 3.73% and 9.28% for the Reglindis variety and between 3.45% and 9.68% for the Rewena variety. Ma și colab. (2015) in his study they showed that fructose and sucrose were the main components of soluble sugars in cultivated

fruits, while fructose and glucose were the main elements of sugars in wild fruits [19]. The increase of dry matter content and total sugar is due to the hydrolysis of the starch contained in immature apples. In their study, Bart et al. (2008) and Mureşan et al. (2015) have demonstrated that starch accumulation occurs between the 35<sup>th</sup> and 84<sup>th</sup> days after full flowering, reaching its maximum value around the 84<sup>th</sup> day [20, 21].

The acidity decreased during fruit growth. Thus, values between 1.83% and 1.20% were registered for the Coredana variety, between 2.20% and 1.50% for the Golden Resistant variety, between 2.60% and 1.90% for the Reglindis variety and between 2.95% and 2.24% for the Rewena variety. The highest acidity was recorded for the Rewena variety, followed by the Reglindis, Golden Resistent and Coredana varieties. The malic acid takes up about 90% of the total content of organic acids [22]. The acidity content decreases slightly during ripening. This could be due to the degradation of citric acid, the transformation of acids during respiration, their conversion into sugars and their subsequent use in the metabolic process in the fruit [16, 23, 24]. At the same time, the processes involved in the metabolism and accumulation of malic and citric acid in mesocarp cells are under both genetic and environmental control. [25]. Many agronomic studies have shown the impact of cultural practices, including irrigation, mineral fertilization, temperature, thinning [26, 27, 28].

The pH values of the apple pulp do not change significantly. They increase slightly from 3.02 to 3.13 for the Coredana variety, from 2.78 to 3.12 for the Golden Resistant variety, from 3.02 to 3.45 for Reglindis and from 2.20 to 2.94 for Rewena. Zheng et al. (2012) reported similar results for Fuji variety [29].

Metabolic changes in sugars and organic acids in fruits play an important role in fruit yield and quality. These determine the organoleptic characteristics of the fruit. Soluble sugars determine the sweetness of apple fruits, and organic acids are responsible for acidity. These obvious transformations of the fruit, which exist in the ripening phase, are perceived both through the human senses and through the laboratory apparatus. Much more complete is the index derived from the sugar / acidity ratio (TSS / AT), which is more strictly related to the quality of the fruit in relation to the unique values of TSS and AT. However, the relationship can vary from year to year [30].



**Figure 5.** Dynamics of ratio TSS/TA during the development of apple fruits of the varieties Coredana, Golden Delicios, Reglindis, Rewena.

Source: authored.

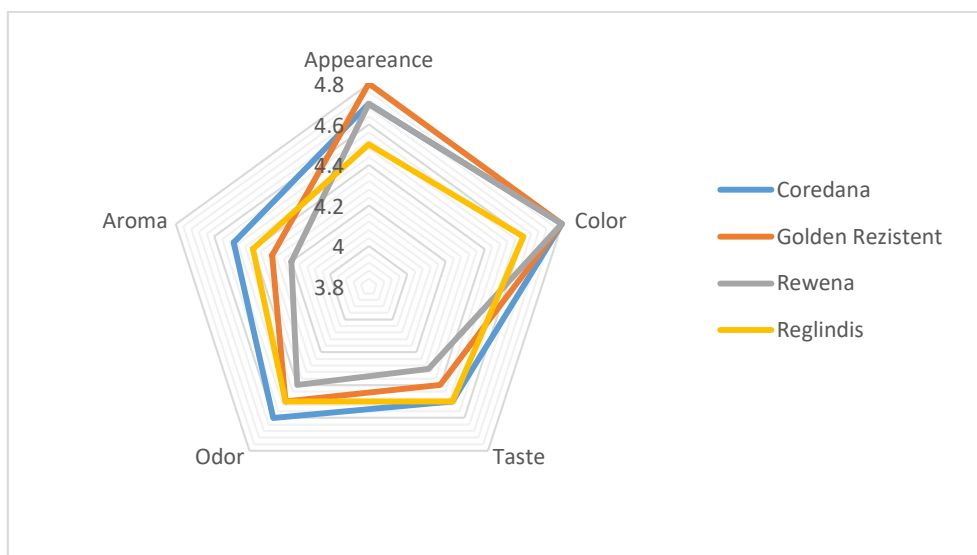
This index serves as an industrial indicator, because the balance between sugars and organic acids influences the taste of the beverage [22]. Sugar / acidity indices of ripe apple varieties Idared and Crips Pink, studied by Bandić et al. (2019), were 28 and 35, respectively. Alberti et al. (2016) demonstrated in his paper that unripe apple fruits showed a ratio of less than 20, which is suitable for industrial processing [31].

Based on the determined values of the total carbohydrate content and the titratable acidity, the TSS / TA indices were calculated for all 4 varieties of apples studied in the given paper and were presented in figure 5.

The results obtained for the 4 apple varieties demonstrate that, in order to obtain the acidifiers, the unripe apples must contain dry matter substances with values between 6.3°Brix to 12.8°Brix. In this phase they accumulate carbohydrates 3.45% - 11.18%, have a titratable acidity from 1.20% to 2.95% (expressed in malic acid) and pH values from 2.20 to 3.45, and the sugar / acidity index will be between values 2.27 and 10.67.

Sensory evaluation of unripe apple extracts was also effectuated. Currently, instrumental sensory analyzers are widely used. However, some researchers insist on organoleptic evaluation by a group of experts consisting of trained food technologists [32, 33].

The studied extracts were sensorially analyzed by 8 evaluators, using a 0-5 – point rating system. Each evaluator recorded the results in their own sensory evaluation sheet. A score value from 0 to 5 was given for each sensorial characteristic. The average scores were computed based on the results. The results are shown in Figure 6.



**Figure 6.** Spider diagram of organoleptic characteristics in unripe apple extracts of 4 varieties Coredana, Golden Delicios, Reglindis, Rewena.

Source: authored.

According to the descriptive evaluation, it was found that the studied samples show relatively clear juice (depending on the method of obtaining). The color was from yellow-straw to light-brown. The taste is intensely acidic and pleasant, slightly sweet, pleasant, specific to the variety, without foreign taste and odor. The aroma was pleasant, specific to unripe apple, expressed moderately, characteristic of apple varieties.

## Conclusions

The unripe apple fruits of 4 varieties were studied: Coredana, Golden Rezistent, Rewena and Reglindis. The fruits were harvested during ripening period at 45<sup>th</sup>, 58<sup>th</sup>, 71<sup>st</sup>, 84<sup>th</sup> and 97<sup>th</sup> days after the full bloom phenophase.

The diameter and mass of the fruits during development have continuously increased for all the analyzed apple varieties. Moisture content (83.20% –87.82%) and pH (2.78–3.45) values does not change significantly for all 4 varieties studied. The dry matter content has increased considerably and highest values of this index were 11.9–12.8°Brix. There are unexpected increases in dry matter around the 84<sup>th</sup> day after the full bloom. The acidity decreased during the fruit development. The highest values were recorded for the Rewena variety with values between 1.83% and 1.20%, followed by the Reglindis variety (2.95% and 2.24%), Golden Rezistent (2.60% and 1.90 %) and Coredana (2.20% and 1.50%). The total sugar content increases significantly during fruit development, registering values between 3.87% and 11.18% for the Coredana variety, between 4.65% and 10.3% for the Golden Resistant variety, between 3.73% and 9.28% for the Reglindis variety and between 3.45% and 9.68% for the Rewena variety. The sugar / acidity index will be between values 2.27 and 10.67.

The results of this study indicate that provide informations regarding the optimal use of the unripe apple varieties studied in order to process and obtain different products (especially natural acidifiers). The products obtained will contain organic acids and valuable nutrients. They can be used as a source of acidity in the food industry (manufacture of juices, beverages, preserves), substituting acidifiers of chemical origin and improving the nutritional value of food.

At the same time, the recovery of unripe apples, obtained by regulating the fruit load on the tree or following physiological falls, will contribute to increasing sustainability through the efficient use of vegetale agricultural waste, using it as a raw material.

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CZU 613.2:641.562:546.72



## GENERIC ALGORITHM SOLUTION IN ESTIMATION OF THE IRON ABSORPTION POTENTIAL FROM COMPLEX SCHOOL MEALS

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**Abstract.** New analytical tools to study iron bioavailability are proposed in this article. An algorithm was devised to predict dietary iron absorption from school meals based on the contents of dietary factors that have the ability to promote or inhibit heme or non-heme iron absorption. The highest absorption rate of iron from representative meals was observed in the presence of ascorbic acid (27,73%) or meat ingredients (27,70%), and the lowest absorption rate – in the presence of Ca (12,40%), tannins (5,83%) and polyphenols (5,36%). Relationships between quantities of total iron intake from foods (dialyzable iron, *in vitro* assay) and the value of nutritional factors in those are described as exponential equations allowing calculations at any stationary state. In elaborated formula the rate of iron absorbance can be predicted considering one, two or three nutritional factors at the same time. The results emphasize the fact that it is important to understand the meal composition for the correct estimation of iron bioavailability.

**Keywords:** *absorption coefficient of iron, algorithm solution, complex school meals, gastrointestinal digestion in vitro, iron absorbance prediction, rate of iron absorbance.*

**List of symbols:** *PHT – phytates, AA – ascorbic acid, PHP – polyphenols, TN – tannins, TA – tannic acid, Ca – calcium, MP – meat products, RDI – recommended daily intake.*

**Rezumat.** În articol sunt propuse noi instrumente analitice pentru a studia biodisponibilitatea fierului. A fost conceput un algoritm pentru a prezice aportul alimentar de fier din mesele școlare, pe baza conținutului de factori dietetici care au capacitatea de a promova sau inhiba absorbția de fier hem sau non-hem. Cea mai mare rată de absorbție a fierului din mesele reprezentative a fost observată în prezența acidului ascorbic (27,73%) sau a ingredientelor din carne (27,70%), iar cea mai mică rată de absorbție – în prezența Ca (12,40%), a taninurilor (5,83%) și polifenolilor (5,36%). Relațiile dintre aportul total de fier din alimente (fier dializabil, testări *in vitro*) și valoarea factorilor nutriționali sunt descrise ca ecuații

exponențiale, care permit calcule în orice stare staționară. În formula elaborată, rata de absorbție a fierului poate fi prezisă luând în considerare unu, doi sau trei factori nutriționali concomitent. Rezultatele subliniază faptul că este important să înțelegem compoziția mesei pentru estimarea corectă a biodisponibilității fierului.

**Cuvinte cheie:** *coeficient de absorbție a fierului, algoritm, mese școlare complexe, digestie gastrointestinală in vitro, predicție absorbție a fierului, rata de absorbție a fierului.*

**Lista simbolurilor:** *PHT – fitati, AA – acid ascorbic, PHP – polifenoli, TN – taninuri, TA – acid tanic, Ca – calciu, MP – produse din carne, RDI – aport zilnic recomandat.*

## 1. Introduction

Iron performs many physiological functions in the human body, one of the most obvious being the function of erythrocyte formation and the transport of oxygen to organs and tissues) [1, 2]. Iron in the human body is an integral part of many enzymes and proteins that are necessary for metabolic processes – the destruction and utilization of toxins, cholesterol metabolism, and the conversion of calories into energy [3 - 5]. It also helps the body's immune system to deal with aggressors [6, 7].

Currently, population of the Republic of Moldova is having products of vegetable origin from which iron is insufficiently assimilated [8-9]. For this reason, even in the conditions of sufficient nutrition, the majority of the population suffers from a chronic deficiency of iron and calcium, which causes the body predisposition to nutritional diseases [10]. According to statistical data, the incidence of blood and hematopoietic diseases in the Republic of Moldova per 1000 inhabitants in the 2010-2020 years varied between 48,1 and 50,1, data that far exceed this index in European countries [11].

The greatest risk for iron deficiency are groups of adolescents (12 - 15 years old), followed by children (6 - 8 years old) [12 - 14]. The results of the laboratory investigations reveal the presence of hypohemoglobinemia up to 10% of the norm for 43,5% of the total number of investigated children, up to 20% – 18,3% and up to 20-30% – for about 1% [15].

The absorption of iron from food rations depends not only on the total iron content in them, but also on the ratio of animal and plant products, as well as on substances that enhance or inhibit its absorption in the gastrointestinal tract. The absorption of iron from predominantly plant-based diets is usually low, since they contain substances that inhibit the absorption of this macronutrient – phytates, tannins, calcium salts [16, 17].

A sufficient amount of meat and fish, which contain organic heme and non-heme iron, as well as the nutritional factors that increase the probability of its absorption are the guarantee of optimal absorption of iron.

Unfortunately, there are currently no practical models for predicting iron absorption potential based on dietary nutritional composition.

## 2. Materials

This study was conducted in order to estimate the level of total iron intake and dialyzable iron by intestinal digestion *in vitro* of the food rations of institutionalized children as well as to estimate the impact of enhancing and inhibiting factors on iron absorption that are present in the food rations [18]. The steps of providing this research are the following:

Step 1. *In vitro* estimation of the bioavailability of iron from the complex ration of institutionalized children, aged 7 - 16 years.



Step 2. Evaluation of anti-nutritional factors that must have been taken into consideration.

Step 3. Elaboration of the algorithm that would allow the estimation of the rate of absorption of hemic and non-hemic iron from foods.

The investigations were carried out within 12 days in order to take into account daily variation.

### **3. Research methods**

**Samples preparation.** The foods were homogenized and after that they were exposed to determination of nutritional compounds or exposed to simulating conditions of digestion. The foods from representative meals were mixed with distilled water and homogenized in a blender to a creamy consistency, so as to give approximately 10 g dry matter/100 g homogenate.

The Mosen simulation method was applied for homogenates of foods to reproduce the digestive conditions on the stomach level (in the presence of pepsin, 150 mg/100g substrate, digestive strength activity of 250000 FCC un/mg, at pH=2 (0,01N sol. HCl)) and then on the intestine level (in the presence of trypsin, 150 mg/100g substrate, digestive strength activity of 600 E un/mg, at pH = 8.. .8,2 (0,08 N sol. NaHCO<sub>3</sub>) [19].

The steps of the simulation of the stomach or intestine digestion had duration of 2 hours each one, were carried out at 37±1 °C with stirring at 60 g<sup>-1</sup>. The aliquots for the analysis were taken every 30 min. of the digestion process.

Each aliquot of partially digested foods was subjected to centrifugation (10 min. at 6000 g<sup>-1</sup>), then the supernatant (about 1 ml) was analyzed to quantify the amount of dialyzed products - iron, calcium, soluble phytates.

**Investigations of nutritional factors.** The soluble Fe in prepared samples was determined by the spectrophotometric method at 535 nm, using as an extraction medium a mixture of hydroxylamine and trichloroacetic acid and as the chromogenic reagent the bath-phenanthroline-disulfonic acid disodium salt (BPDS) [20]. The total iron content of samples was determined after solid or liquid mineralization of the samples [21, 22].

The phosphorus content in the samples was determined in the reaction with ammonium molybdate-vanadate at 440 nm [23]. The content of phytates in the products of vegetal origin was determined using a recalculation factor of 1:3,55 [24]. The quantity of dialyzed phytates was determined in correlation with rate of accumulation of soluble Ca during gastrointestinal digestion.

The total Ca content was determined by atomic absorption spectroscopy method after sample mineralization [25]. The limit of detection of the method is 0,2 mg Ca /kg of sample, the linearity range – 0,2-200 mg Ca /kg of sample. Determination of soluble Ca content was performed by titration with Trilon B [26]. The ascorbic acid content was determined by titration with 2,6-dichlorophenol-indophenol [27].

The calculation of nutrition factors present in the children meals were performed using Excel software.

**Statistical analysis.** Experimental testing was carried out in triplicate for each sample and standard. Descriptive statistical analysis was performed using Excel software for calculating the means and standard deviations. The mathematical expression of influence of nutritional data of meals on the value of coefficient of iron absorbance was obtained using SPSS (version 13.0 Windows program).

#### 4. Results and discussions

**Nutritional value of complex meals.** The nutritional study highlighted the fact that the average calorific value for the examined 12 days was of 2069 kcal /day (Table 1), which represents 82,8% of the average daily requirement of 2500 kcal /day. The content of macronutrients, according to the performed calculations for this period, may be distributed as follows: proteins – 71,39 g / day, i.e. 79,3% compared to the physiological norm (on average 90 g /day); lipids – 60,36 g / day, i.e. 67% compared to the recommended norm; sugars – 335,4 g / day, i.e. 93,17% (on average 360 g /day). The average daily intake of iron calculated from recipes was 17,2 mg Fe /day, what constitutes 95,6% of the recommended intake (18 mg Fe /day). But the average content of total iron, determined in the daily rations of institutionalized children by experimental techniques constitutes only 9,66 mg Fe /day, which covers only 53,75% of the recommended norm.

Table 1

**Level of total iron content in the ration of institutionalized children aged 11 - 17 years in Moldova**

Monitorized days	Energetic value <sup>1</sup> (kcal/day)	Total iron content (mg/day)		Total iron from RDI <sup>2</sup> (%)
		Calculated	Experimental	
1	1911,9	15,44	9,54±0.03	53,0±0.2
2	2006,9	16,73	10,11±0.07	56,6±0.4
3	1767,0	13,05	8,19±0.06	45,5±0.3
4	1995,0	14,63	9,22±0.05	51,2±0.3
5	2392,7	18,23	11,75±0.09	65,3±0.5
6	2459,9	21,25	12,09±0.08	67,2±0.4
7	1997,8	17,03	9,75±0.06	54,2±0.3
8	2016,5	19,05	9,92±0.07	55,1±0.4
9	1876,4	15,74	8,14±0.05	45,2±0.3
10	1991,2	18,05	9,37±0.07	52,1±0.4
11	2005,6	17,63	8,89±0.06	49,4±0.3
12	2411,5	19,74	8,95±0.05	49,7±0.3
<b>Mean</b>	<b>2069,0</b>	<b>17,20</b>	<b>9,66±0.09</b>	<b>53,7±0.5</b>

Note. Recommended energetic value for girls – 2400-2700 kcal/day, boys – 2500-2700 kcal/day [39]. Recommended daily iron intake – 18 mg/day, or 7,2 mg Fe/1000 kcal [28].

Research done in the conditions of gastrointestinal digestion *in vitro* showed that the level of dialyzed iron (i.e. available for gastrointestinal absorption) reached a value of 1,84 mg /day (Table 2), which constitutes 18,6% compared to total iron.

An important indicator of rational nutrition is the ratio of whatever macronutrients to energy value of meal, in this case – 7,2 mg Fe /1000 kcal [28]. According to the experimental determinations of the analyzed meals, this indicator was relatively low, about 4,67 mg Fe /1000 kcal. In the same time the level of dialyzable iron, experimentally determined after gastrointestinal digestion research *in vitro* is extremely low and constitutes only 0,89 mg Fe /1000 kcal.

Table 2

**Level of dialyzed iron content in the ration of institutionalized children aged 11-17 years in Moldova**

Monitorized days	Dialyzed iron content, experimental data (mg/meal)				Dialyzed iron (% from total iron)
	Breakfast	Lunch	Dinner	Per day	
1	0,26±0,02	0,87±0,03	0,62±0,05	1,75±0,05	18,3
2	0,31±0,05	0,87±0,07	0,81±0,05	1,99±0,07	19,7
3	0,29±0,05	0,50±0,02	0,37±0,05	1,16±0,05	14,2
4	0,34±0,06	0,79±0,06	0,82±0,05	1,95±0,06	21,1
5	0,62±0,05	0,76±0,05	0,69±0,05	2,07±0,05	17,6
6	0,42±0,05	0,68±0,03	1,05±0,05	2,12±0,07	17,5
7	0,53±0,06	0,63±0,06	0,69±0,05	1,85±0,06	18,9
8	0,37±0,05	0,38±0,03	0,43±0,05	1,27±0,05	12,8
9	0,45±0,03	0,80±0,05	0,67±0,06	1,92±0,06	23,6
10	0,49±0,05	0,99±0,01	0,57±0,05	2,05±0,05	21,8
11	0,27±0,02	0,42±0,04	0,87±0,04	1,56±0,04	17,5
12	0,52±0,07	0,70±0,03	0,67±0,05	1,88±0,07	21,1
<b>Mean</b>	<b>0,40±0,04</b>	<b>0,69±0,04</b>	<b>0,68±0,04</b>	<b>1,84±0,07</b>	<b>18,6</b>

**Note.** Dialyzed Fe was determined after 4 hours of digestion *in vitro* (2 hours of modeled gastric digestion in the presence of pepsin at pH=2, and 2 hours of modeled intestinal digestion in the presence of trypsin at pH=8).

According to the nutritional calculations, the average content of phytic phosphorus, recalculated in phytic acid was 1,85 mol /day (Table 3). After 4 hours of gastrointestinal digestion *in vitro* only 16,35% of the presented phytates were degraded due to enzymolysis in the presence of gastrointestinal enzymes. This explains also the very low percentage of dialyzable calcium (5,4%), which confirms the fact that the stability of Ca phytates compounds is very high [29]. The analysis of the obtained data denotes the need for improving the nutrition of the institutionalized children in accordance with the nutritional principles [30], especially for the compartment of macroelements (Fe and Ca). Achievement of this goal involves actions for increasing the contribution of essential macro- and microelements as well to ensure their bioavailability [31, 32]. In particular, it is recommended to use in children's nutrition foods that are rich in iron (meat, fish and beans). Also, fortified products with an increased bioavailability of iron can be used [33, 34].

The level of absorption rate of iron in foods is influenced by the individual status of the organism in the iron, by the content of the iron and its structure forms (hemic and non-hemic iron) in the ration, as well as by all the nutritional factors, present in the ration.

It is known that some dietary factors (free amino acids, proteins of animal origin) have a positive influence on the bioavailability of iron in foods, while other factors (phytates, tannins and other polyphenols, oxalates, calcium) possess the ability to inhibit absorption of dietary iron [35 - 37]. It is also necessary to take into account the interactions of various factors present in the ration. Thus, the working hypothesis was formulated as follows – the degree of absorption of iron in food is the result of the action of all the factors present in food.

Table 3

**Impact of anti-nutrients (phytates, calcium) on the level of soluble iron content/day of the ration of institutionalized children aged 11-17 years in Moldova**

Monitored days	Calculated macronutrients (g)			Calculated micronutrients (mg)			Phytical P (mg)	Total phytates (mol)	After 4 hours of gastrointestinal digestion <i>in vitro</i>	
	Proteins	Fats	Sugars	Ca	Fe	P			Dialysed Fe (%)	Hydrolyzed phytates (%)
1	64,69	33,82	336,42	531,7	15,44	1034,0	992,6	1,5	18,3±0,03	15,75±0,09
3	57,11	37,9	303,13	604,4	14,63	963,3	924,8	1,4	14,2±0,01	17,29±0,11
5	86,42	100,9	347,16	863,2	18,23	1565,2	1502,6	2,28	17,6±0,02	14,83±0,13
7	100,5	61,84	370,9	1003	19,74	1799,9	1727,9	2,62	19,7±0,03	21,37±0,15
9	62,7	57,4	327,2	627,4	15,74	1256,7	1206,4	1,83	23,6±0,04	15,91±0,09
11	56,9	70,3	327,6	511,1	16,73	1046,0	1004,2	1,52	17,5±0,02	12,96±0,08
<b>Mean</b>	<b>71,38</b>	<b>60,36</b>	<b>335,4</b>	<b>690,1</b>	<b>16,75</b>	<b>1042,7</b>	<b>1226,4</b>	<b>1,85</b>	<b>18,48±0,03</b>	<b>16,35±0,15</b>

The absorption coefficient of the iron was analyzed in relation to the reference samples, free of anti-nutrients, in which the degree of absorption of the iron was considered maximum – of 22,1% with reference to the total iron content [38]. Based on the research carried out, on the analysis of rations of institutionalized children, the authors developed an algorithm, aimed to highlighting the influence of the various compounds present in the ration on the rate of iron solubility in the gastrointestinal media.

**Influence of phytates.** In order to evaluate the impact of phytates present in foods on the absorption coefficient of iron, the relationship between the iron solubility of each representative sample and the total iron content, the total phytate content, and also the rate of enzymolysis of the phytates during gastrointestinal digestion was established for the examined samples (12 days · 3 meals = 48) [39]. The mathematical analysis was performed by extrapolation of these functions to the null content of the phytates in the representative meal, where iron absorption is considered optimal (22,1± 0.18) %.

Comparison of obtained data allowed establishing of the following relationship between the coefficient of iron absorption and phytates content of the food:

$$K_{abs.}(Fe) = 10^{-0,3 \cdot \log(1+0,2833 \cdot C_{PHT})} \quad (1)$$

where  $C_{PHT}$  is the content of phytates in the representative meals, expressed in mg.

The value of correlation coefficient was estimated to be:  $r^2 = 0,926$  ( $n = 48$ ).

Thus, the effect of phytates on the absorption coefficient of iron from foods is significant. If the content of the phytates, for example, in a representative meal is null, such as  $K_{abs.}(Fe) = 1$ , the absorption of iron can be considered to be 22,1%. If 353 mg of phytates are consumed (from bread, for example), and the rate of hydrolyzed phytates does not exceed 15%, in this case  $C_{PHT}$  will be 300 mg. Substituting this value into equation (1), we obtain:

$$K_{abs.}(Fe) = 10^{-0,3 \cdot \log(1+0,2833 \cdot C_{PHT})} = 10^{-0,3 \cdot \log(1+0,2833 \cdot 300)} = 0,2637.$$

Thus, the absorption potential of iron from the representative meal will constitute  $22,1 \cdot 0,2637 = 5,83\%$  of the total ingested quantity of iron. Obviously, the algorithm does not take into account the influence of the iron status of the organism, a factor that has a decisive influence on the absorption of iron from foods.

**Influence of ascorbic acid (AA).** According to the authors [40], the promoter effect of ascorbic acid is much more prominent in the presence of iron absorption inhibitors, especially phytates and polyphenols. Thus, the addition of 100 mg AA in beverages, in the presence of tea tannins increased the iron absorption by 4,14 times, and also, in the presence of phytates the absorption of iron is increased by 3,14 times. But the addition of a similar amount of AA to a representative meal (which contained meat, potatoes and milk, but without of these inhibitors of iron absorption) increased iron absorption only with 67%. The addition of 50 mg of AA in wheat flour rolls increased the average iron absorption from 22,4 to 37,6%. Investigations have been conducted *in vivo* with the labeled atoms of iron.

These bibliographic data indicate that the promoter effect of AA is strongly correlated with the factors present in the diet. As an antioxidant, AA facilitates the reduction of ferric iron into ferrous iron, which has much weaker chelating properties than ferric iron with reference to polyphenols and phytates present in the diet [41]. Therefore it is obvious that the promoting effect of AA will be more significant, since the binding rate of iron by chelating inhibitors will be higher. These regularities were taken into account for the formulation of the algorithm that describes the promoter effect of A in the presence of phytates. Also, for the elaboration of the algorithm the following conditions have been met:

- in the absence of AA inhibitors, a promoter effect is proportional to the administered dose:

$$K_{abs.}(Fe) = 1 + 0,01 \cdot C_{AA} \quad (2)$$

where  $C_{AA}$  represents the AA content, expressed in mg /representative meal [42].

- in the presence of phytates, the promoter effect of AA is manifested more significantly, when the phytate content is higher.

Because in the analyzed representative meals the phytates were present in variable quantities, the data were analyzed specifically for such cases. The regression lines that describe this relationship have a different linear slope depending on the logarithm of  $C_{AA}$ . The correlation coefficients ( $r^2$ ) ranged from 0,837 to 0,877 ( $n=48$ ). The analysis of the obtained regression equations allowed us to establish the following equation, which expresses the relation between the absorbability of the iron on the one hand and the AA content and of the phytates on the other:

$$K_{abs.}(Fe)=0,01 \cdot [1+0,01 \cdot C_{AA} + \log(1+0,2833 \cdot C_{PHT})] \cdot 10^{0,8875 \cdot \log(1+C_{AA})} \quad (3)$$

The correlation coefficient for the obtained equation had the value:  $r^2 = 0,995$  ( $n=48$ ). The promoter effect of AA described by equation (3), was similar for the case of the presence in the meals of meat products (that contain hemic iron) and milk products (that contain calcium).

To compare the promotional effect of AA in the absence or presence of phytates, we admit that a representative meal contained 30 mg of AA (from fresh fruit, fruit juices). In the absence of phytates and other iron absorption inhibitors, the iron absorption coefficient is determined from the relationship (2).

$$k_{abs.}(Fe) = 1 + 0,01 \cdot C_{AA} = 1 + 0,01 \cdot 30 = 1,3.$$

Thus, the bioavailability of iron from a complex meal, but that is lacking in antinutritional factors, in the presence of AA will constitute:  $22,1 \cdot 1,3 = 27,73\%$ .

For comparison, if the concomitant presence of 353 mg of phytates is allowed, where the rate of enzymatic dephosphatization in the gastrointestinal tract does not exceed 15%, the iron absorption coefficient calculated according to the relationship (3) will be:

$$k_{\text{abs.}}(\text{Fe})=0,01 \cdot [1+0,01 \cdot 30+\log(1+0,2833 \cdot 300)] \cdot 10^{0,8875 \cdot \log(1+30)} = 0,4258;$$

which means that  $22,1 \cdot 0,4258 = 9,41\%$  of the total iron present in the food intake of a representative meal will be absorbed.

Comparing this value with the absorption coefficient, obtained in the presence of the same quantities of phytates, but in the absence of AA ( $k_{\text{abs.}}(\text{Fe}) = 0,2637$ ), it becomes obviously that the promoter effect of AA is especially important in the presence of inhibitors:

$$\frac{0,4258}{0,2637}=1,615 \quad (\text{for } 30 \text{ mg of AA and } 353 \text{ mg of phytates}).$$

In the absence of inhibitors, the protomotor effect of the same amounts of AA will be of 1.3 times more evident.

A practical problem, related to the application of this algorithm, resides in the difficulty of estimating the AA content at the time of consumption, because the method and duration of applied heat treatments significantly influence the AA content. As a rule, the table data regarding to the composition of foods are used for the assessment of AA content, although the differences between the experimental data and the table data are significant.

**Influence of polyphenols.** The inhibitory effect of tea, coffee, red wine on iron absorption is confirmed in several bibliographic studies [10, 43]. This effect is attributed to the presence of polyphenols. Gallium groups with the 3 adjacent hydroxyl groups, specific for polyphenols, are considered the main structures, which fix iron by forming chelates [44]. In particular, ferric iron is fixed, which explains the role of AA in diminishing the inhibitory effect phenolic compounds on iron absorption.

The inhibition of the absorption of iron by coffee is attributed, in particular, to the important content of chlorogenic acid in this product, although the action of this compound is less marked than of the gallium groups. It is estimated that the equimolar amounts of gallic and chlorogenic acids have a relative effect of inhibition of iron absorption of 6:1. Thus, it is stated that a 200 ml cup of tea reduces the absorption of iron in consumed foods on average by 75-80%. A 100 ml cup of coffee reduces iron absorption by an average of 60%. When tea or coffee is served at the same meal with a 100 g portion of meat, the iron inhibiting effect is reduced by 50%.

The lower inhibitory effect of coffee in comparison to the action of tea is explained by the fact that coffee considerably stimulates gastric secretion (production of HCl). The research based on iron absorption in individuals with hypochlorhydria indicates a much stronger inhibitory effect of the coffee (the rate of absorption of iron was 0,19 to 0,39 – for healthy people) [12]. In order to evaluate the effect of tea or coffee on the absorption of iron, it has established a factor equivalent of 15 mg of tannic acid (TA) for a cup of ordinary coffee (with or without milk) and 30 mg TA for a cup of tea.

Taking into account this factors, as well as the presence of meat or fish products in the ration ( $m_{\text{MP+FP}}$ , g), the effect of polyphenols on the absorption coefficient of iron in foods can be expressed by the empirical relation:

$$K_{\text{abs.}}(\text{Fe})=(1+0,01 \cdot m_{\text{MP+FP}}) \cdot 10^{0,4515- [0,715-0,1825 \cdot \log(1+C_{\text{AA}})] \cdot \log(1+A_{\text{TA}})} \quad (4)$$

where the content of  $C_{AA}$  and  $C_{TA}$  is expressed in mg/meal. For the examined cases ( $n=48$ ), the correlation index was:  $r^2=0,978$ .

The deduced empirical relation allows to estimate the summary effect of promoters (meat and fish products, AA) and inhibitors (tannic acid equivalent of polyphenols) present in a representative meal on the absorption coefficient of iron from foods. For example, if 50 g of meat is consumed at the same time with 353 mg of phytates with hydrolysis rates of 15% (a slice of bread), 30 mg of AA and 30 mg of TA (a cup of tea), then in this case the absorption coefficient of iron will have the value:

$$k_{abs.}(Fe)=(1+0,01 \cdot 50) \cdot 10^{0,4515 - [0,715 - 0,1825 \cdot \log(1+30)] \cdot \log(1+30)} = 0,927;$$

that means, that the absorption rate of iron can be evaluated at 20,5%.

In the absence of AA, but in the presence of meat and fish products the absorption coefficient of iron will constitute 0,628 (the calculation is performed based on the same equations (4).

In the absence of AA, but in the presence of meat and fish products, we will have:

$$k_{abs.}(Fe)=(1+0,01 \cdot 50) \cdot 10^{0,4515 - 0,715 \cdot \log(1+30)} = 0,3614,$$

that means, that the absorption rate of iron can be evaluated at  $\approx 8\%$ . Thus, the promoter effect of AA in the presence of polyphenols (TA) is very significant and constitutes  $\frac{0,927}{0,3614} = 2,565$ .

In the absence of both iron promoters - AA and meat and fish products, the absorption coefficient of iron in foods, consumed at the same time with a cup of tea, will be even lower:

$$k_{abs.}(Fe)= 10^{0,4515 - 0,715 \cdot \log(1+30)} = 0,2428;$$

that means, that the absorption rate of iron can be estimated at 5,36%.

This algorithm allows to take into account both the presence of inhibitors factors, and promoters.

**Influence of calcium.** The inhibitory effect of calcium on the absorption rate of iron from foods with complex structure has been reported in a considerable number of studies [45 - 47]. As the nature of the inhibitory effect of calcium on the iron absorption from foods was not exactly set, some authors have assumed that in the case of complex foods the formation of mixed iron and calcium chelated compounds are taken place (the last being more abundant). It is also assumed that the negative effect on iron absorption manifested by Ca is due to the inhibition of iron absorption by enterocytes in the presence of a significant amount of Ca. It is considered that the abundance of calcium in meals is also associated with a decrease in the amount of serum ferritin, which produces a great biological relevance regarding to the iron absorption potential [48].

The effect of calcium on the absorption coefficient of iron in foods can be expressed by the empirical relation:

$$k_{abs.}(Fe)=0,3981 + \left\{ \frac{0,6019}{1+10^{-[2,022-\log(C_{Ca}+1)] \cdot 2,919}} \right\} \quad (5)$$

If 300 mg of Ca is consumed in a representative meal, then the absorption coefficient of iron will be:

$$k_{abs.}(Fe)=0,3981 + \left\{ \frac{0,6019}{1+10^{-[2,022-\log(300+1)] \cdot 2,919}} \right\} = 0,562;$$

That means, that the rate of iron absorbance can be evaluated at 12,4%. Concentration of calcium is expressed in mg /representative meal.

If the consumption of Ca in a representative meal is of 500 mg, then:

$$k_{\text{abs.}}(\text{Fe})=0,3981 + \left\{ \frac{0,6019}{1+10^{-[2,022-\log(500+1)] \cdot 2,919}} \right\} = 0,404;$$

which corresponds to an iron absorption rate of 8,93%.

The inhibitory effect of calcium on iron absorption is striking, especially at high calcium concentrations. At low concentrations of calcium in meal (100-200 mg), the inhibitory effect of calcium is non-significant [49].

**Influence of meat and fish products.** Many researchers showed that meat and fish products increase the absorption of non-hemic iron. Currently, the promotional mechanism of these products is not completely elucidated, as well as the magnitude of this effect for different product groups. According to the study [50], the absorption rate of iron from foods, depending on the meat and fish content of the meal (in the absence of iron absorption inhibitors), is expressed by the linear relationship:

$$k_{\text{abs.}}(\text{Fe})=1+0,00628 \cdot m_{\text{MP+FP}} \quad (6)$$

where,  $m_{\text{MP+FP}}$  represents the summarized quantity of meat and fish products (g) /representative meal.

Because of, in the examined case meat and fish products were served as a complex meals (in the presence of phytates in bread rolls), the combined effect of these two factors on the absorbability of iron was analyzed. The combined effect of these two factors is expressed by the algorithm:

$$k_{\text{abs.}}(\text{Fe})=1+0,00628 \cdot m_{\text{MP+FP}} \cdot (1- 0,0017 \cdot C_{\text{PHT}}); \quad (7)$$

So, the promotional effect of meat and fish products is noticeable also in the presence of phytates ( $r^2=0,976$ ;  $n=48$ ). If 50 g of meat or fish are consumed, then the absorption coefficient of iron in the absence of phytates will be of:

$$K_{\text{abs.}}(\text{Fe})=1+0,00628 \cdot 50 =1,314;$$

which corresponds to an iron absorption rate of 27,7%;

In the presence of phytates (353 mg, with the hydrolysis rate of 15%), the absorption of iron will be:

$$K_{\text{abs.}}(\text{Fe})=1+0,00628 \cdot 50 \cdot (1-0,0017 \cdot 300)=1,154;$$

which corresponds to an iron absorption rate of 24,3%.

For performing the calculations according to this algorithm, it is used a recalculation proportion – 1 g of raw meat correspond to 1,3 g of heat treated meat [51].

## Conclusions

**Suggestions for applying the algorithm for assessing the bioavailability of iron in complex foods.** In order to determine the absorption coefficient of iron from a representative meal, it should be proceed in the following way. The average iron absorption of 22.1% is considered as a basic factor. This data is multiplied and influence by the presence of one or more dietary factors specific for foods: phytates factor, AA factor, polyphenols factor, Ca factor and MP factor. The obtained values will represent the percentage of bioavailability of



iron in foods (or the probable absorption). Subsequently this quantity data might be adjusted to the iron status corresponding to the absorption dose of the experimental sample.

The algorithm can be used to evaluate the iron content availability in foods, for example, from school and students' lunches, for hospitalized persons, for performance athletes, for people doing their military service, etc. The algorithm allows to transfer the data from the area of general nutritional research to amounts of absorbable iron. The main requirement for these calculations is the presence of accurate and detailed information on the nutritional composition of the meals for a sufficient period of time (12 - 14 days).

The algorithm allows to estimate the presumed effects of some dietary changes, for example fortification of the diet with iron, increased consumption of fruits and vegetables, the degree of iron extraction from various types of flour used in the bakery industry, etc. Also, the algorithm allows to estimate the degree of coverage of nutritional requirements for different population groups, groups that are feeding on different styles (vegetarians compared to full diet), that would allow to elaborate reasoned nutritional recommendations.

**Impediments in using.** The basic difficulties in applying of this algorithm lie in the following. A practical problem, which involves certain difficulties, is the estimation of the AA content at the time of consumption, since the type of process and the duration of the applied heat treatment significantly influence the AA content. Phytates have a marked influence on the absorbability of iron, even in relatively small quantities. Progressive dephosphating of phytates which occurs during food processing, changes their impact on the iron absorption coefficient. Thus, if only estimative calculations will be taken into account, given on the initial content of the phytates in the original foods, data with different degree of correlation will be obtained.

In order to outline these practical problems, supplemented data must be used, that indicate both the content of phytates and the content of polyphenols in foods of vegetable origin, expressed in equivalents of elemental components – phytic acid, tannic acid, chlorogenic acid.

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