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Section 1. Biology

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INVESTIGATION OF THE HEPATOPROTECTIVE EFFECT OF ANACARDIUM IN CARBON TETRACHLORIDE- AND ETHANOL–INDUCED HEPATITIS MODELS

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Abstract

Toxic liver injury is among the most common etiological factors of hepatobiliary pathology and is strongly associated with the increasing impact of hepatotoxic xenobiotics from household, industrial, and agricultural chemicals. These exogenous agents not only possess specific mechanisms of action but also trigger universal endogenous damage in hepatocytes through oxidative stress. In this context, polyphenolic compounds with antioxidant properties are considered promising hepatoprotective agents. The present study investigates the hepatoprotective potential of anacardic polyphenol in experimental models of carbon tetrachloride- and ethanol-induced toxic liver injury in Wistar rats. Different doses of the compound were administered orally and intraperitoneally, and its influence on biochemical markers such as total protein, ALT activity, lipid peroxidation products (diene conjugates and MDA), as well as functional indicators (hexobarbital-induced sleep duration) were evaluated. The findings demonstrated that anacardic polyphenol significantly reduced biochemical alterations, restored hepatocellular integrity, and exhibited dose-dependent hepatoprotective activity, with the most effective results observed at 100 mg/kg orally and 5 mg/kg intraperitoneally. These results suggest that anacardic polyphenol may serve as a promising hepatoprotective agent, potentially comparable to established drugs such as Karsil.

Keywords: *toxic liver injury, hepatoprotection, anacardic polyphenol, oxidative stress, ALT, MDA, carbon tetrachloride, ethanol*

Introduction

Toxic liver injury is one of the most common etiological factors of hepatobiliary pathology. It is associated with the increasing exposure to hepatotoxic xenobiotics, including household, industrial, and agricultural

chemicals. These exogenous factors not only have their own specific mechanisms of action, but also trigger a universal and powerful pathway of endogenous hepatocyte damage in the form of oxidative stress (Li, S. et al., 2015). Its products – highly reactive and abundant oxygen metabolites – are responsible for the development of metabolic disorders, membranopathies, functional impairments, mutations, accelerated apoptosis, and other forms of cellular pathology.

At the same time, the multifactorial nature of toxic liver injury requires therapeutic agents with multilevel protective mechanisms, a property currently characteristic of only certain hepatoprotectors (e.g., Legalon, Sylibor, Hepaton). A distinctive feature of modern hepatoprotectors is that they are derived from plant raw materials and contain polyphenolic compounds with antioxidant activity – flavonoids, flavolignans, cinnamic acids, and other bioactive components (Saha, P., et al., 2019).

At present, the share of effective domestic hepatoprotectors on the global pharmaceutical market is relatively small, and they constitute only a minor proportion compared to similar foreign drugs. Therefore, there is an urgent need to identify new agents capable of enhancing liver resistance to toxic injury. Preference should be given to plant-based preparations, which are generally characterized by low toxicity combined with sufficient efficacy and a broad spectrum of therapeutic action (Ma, S., et al., 2025).

Material and Methods

The studies were conducted on 240 mature white Wistar rats of both sexes, weighing 170–280 g, in accordance with international recommendations of the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes. Acute liver injury induced by carbon tetrachloride (CCl_4) was modeled by oral administration of a 50% CCl_4 solution using a metal atraumatic probe. Acute alcoholic liver injury was induced by intraperitoneal administration of a 33% ethanol solution. The studied polyphenolic compound, anacardic acid, was administered to model animals both orally and intraperitoneally (Chiu, Y. J., et al., 2017).

The tested anacardic polyphenol was administered orally at doses of 100, 300, and 500 mg/kg twice daily for 12 days via gastric intubation (tube feeding), and intraperitoneally at doses of 5, 15, and 25 mg/kg twice daily for 12 days. It should be noted that the tested polyphenol was administered 5 days prior to the introduction of the hepatotoxin solution (carbon tetrachloride or ethanol), and then concomitantly for 7 days, i.e., 1 hour before CCl_4 or ethanol administration (Zhang, X., et al., 2022).

Determination of the acute toxicity of the studied drugs was carried out in accordance with methodological guidelines for studying the general toxic effects of pharmacological agents. The functional activity of the liver was evaluated by the duration of sleep in animals, which reflects the state of the microsomal system responsible for the metabolism of xenobiotics, particularly sodium ethaminal. The experiment was conducted according to the method of V. V. Gatsura. After 14 days of administration of the studied preparation to animals with carbon tetrachloride- and ethanol-induced models, sodium ethaminal was injected intraperitoneally at a dose of 40 mg/kg. The sleep duration (in the lateral position) was recorded in minutes. Statistical results were processed and expressed as the arithmetic mean (M) and its standard error (m).

Sodium ethaminal and the studied anacardium polyphenol were administered orally at different doses (100, 300, and 500 mg/kg) and intraperitoneally at different doses (5, 15, 125 mg/kg) under conditions of acute toxic liver injury induced by carbon tetrachloride and ethanol. On the 14th day of substance administration, sodium ethaminal was injected intraperitoneally at a dose of 40 mg/kg. Animals that received the same volume of purified water were used as the control group. According to the obtained results, compared to the control group, administration of anacardin led to a significant and reliable reduction in sleep duration, especially at a dose of 100 mg/kg, which accounted for 55.7%.

The reduction of ethaminal sleep duration during administration of the studied preparations most likely indicates the presence of a hepatoprotective effect, which contributes to maintaining the activity of the liver microsomal system. This system, through

cytochrome P450 participation, provides biotransformation reactions catalyzed by endoplasmic reticulum enzymes. Our research was devoted to determining the optimal therapeutic dose of the studied preparation for normalizing altered biochemical parameters in hepatocytes under conditions of carbon tetrachloride- and ethanol-induced liver damage. To achieve this goal, the effect of the preparation was evaluated based on its ability to normalize all biochemical parameters, including the reduced total protein level observed during cytolysis and the increased activity of the ALT enzyme.

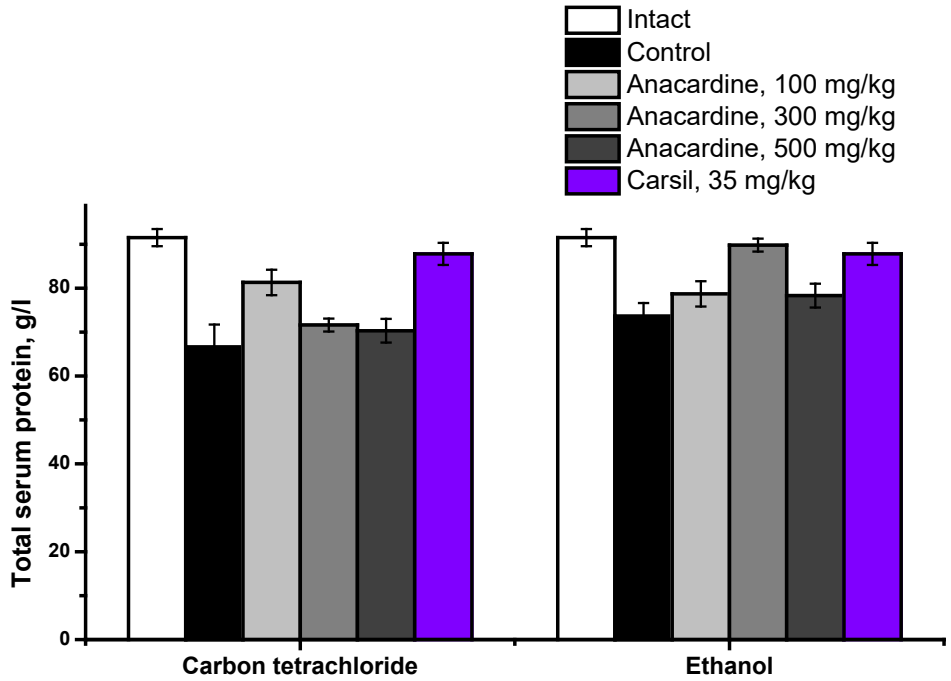
Results

In our experiments, the composition of diene conjugates was initially determined. The content of diene conjugates was expressed in μmol/L. Carbon tetrachloride intoxication disrupted all liver functions: protein-synthetic activity (the total protein level decreased by 27.2%), and severe hepatocellular damage was observed, manifested by an increase in the serum concentration of diene conjugates and TBARS products (MDA), by 41.2% and 175.1%, respectively, compared with the group of intact animals.

When anacardine was administered orally at a dose of 100 mg/kg, the levels of serum lipid peroxidation (LPO) primary products (diene conjugates) and LPO end-products (TBARS-active MDA), as well as total protein, remained significantly elevated compared to intact controls-109.9%, 145.2%, and 88.5% of the control values, respectively.

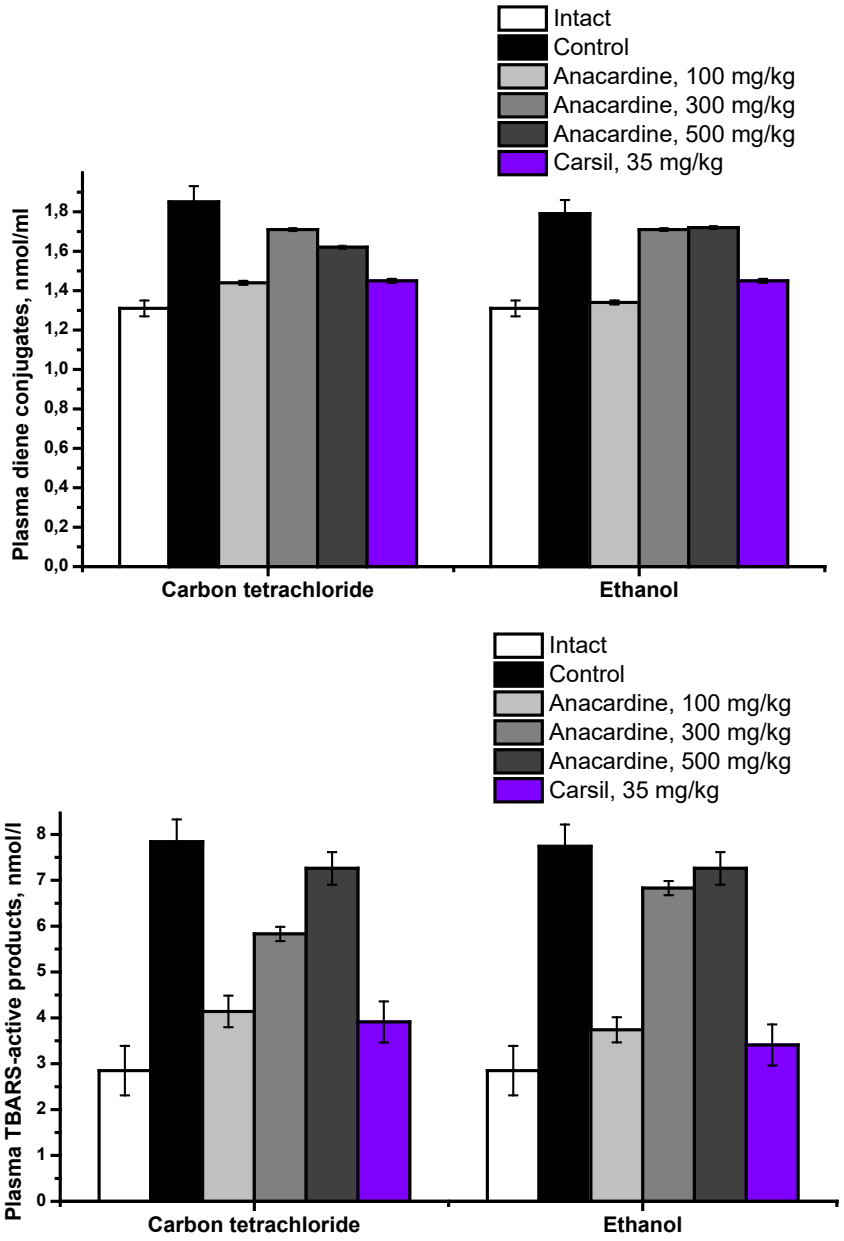
At a dose of 300 mg/kg, anacardine administration, compared to the 100 mg/kg dose, resulted in a significant decrease in serum diene conjugates, TBARS-active products, and total protein levels – by 10.2%, while diene conjugates and TBARS-active products increased by 20.6% relative to controls (Figure 1).

Figure 1. *Changes in the serum total protein level under oral administration of different doses of anacardine in liver toxicity induced by carbon tetrachloride and ethanol*



According to the results obtained in ethanol-induced liver pathology, when the dose was increased to 300 mg/kg, serum total protein concentration decreased by 22% compared with the control, while the levels of diene conjugates and TBARS-active products significantly decreased to 102.29% and 131.22%, respectively. However, these values were still lower than those observed with the 100 mg/kg dose. Subsequent escalation of the anacardine dose to 500 mg/kg did not exert any additional beneficial effect on these parameters and did not lead to significant changes (Figure 2).

Figure 2. *Changes in the levels of diene conjugates and TBARS-reactive substances in blood serum under oral administration of different doses of anacardine in liver toxicity induced by carbon tetrachloride and ethanol*



At the next stage of the study, the doses of intraperitoneal administration of anacardine were determined in order to confirm its efficacy at 5 mg/kg. The effects of different doses (5, 15, and 25 mg/kg) on the dynamics of changes in biochemical markers in models of toxic liver injury induced by carbon tetrachloride and ethanol were investigated. According to the results, administration of the studied polyphenol anacardine by two different routes in the selected pathologies did not show significant differences and demonstrated almost identical outcomes.

The presented data indicate that carbon tetrachloride intoxication impaired all liver functions: protein-synthetic function (total protein decreased by 26.2%), and deep hepatocellular damage was evidenced by an increase in serum diene conjugates and TBA-reactive products (MDA) by 41.2% and 175.1%, respectively, compared to the intact group.

In carbon tetrachloride-induced liver injury, oral administration of anacardine at a dose of 5 mg/kg resulted in serum levels of primary LPO products (diene conjugates), terminal LPO products (TBA-reactive MDA),

and total protein remaining significantly higher than in the intact group-109.9%, 145.2%, and 88.5%, respectively. At a dose of 15 mg/kg, compared to 5 mg/kg, significant decreases were observed relative to the control group: serum diene conjugates, TBA-reactive products, and total protein levels decreased by 10.2%, while diene conjugates and TBA-reactive products increased by 20.6%.

Our subsequent experiments focused on investigating certain biochemical markers, considered indicative in ethanol-induced liver pathology, under the influence of the studied polyphenol anacardine. When the dose was increased to 15 mg/kg, the total serum protein level decreased significantly by 22% compared to the control, while diene conjugates and TBA-reactive products decreased by 102.29% and 131.22%, respectively. However, these parameters remained lower than those observed at a dose of 5 mg/kg. Further increasing the dose of anacardine to 25 mg/kg did not produce positive effects on the above parameters and did not lead to significant changes (Akhmadova, M., et al., 2025).

Discussion

The overall indicators obtained, including integral survival indices, detailed biochemical analysis of serum and liver, and data calculated according to the hepatoprotection coefficient, make it possible to propose a dose of 5 mg/kg as an effective therapeutic dose for intraperitoneal administration of anacardine (Madrigal-Santillán, E., et al., 2014).

In models of carbon tetrachloride- and ethanol-induced hepatitis, comparison of the hepatoprotective effect of anacardine with Karsil showed that, relative to the control, serum diene conjugates decreased by 49%, TBA-reactive products were corrected by 36.4% in serum and 41.7% in liver. Furthermore, the increase in ALT activity, as a marker of cytolysis, and the decrease in total protein content were normalized under the influence of the applied preparation.

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Section 2. Computer science

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SKELETON-BASED HUMAN ACTION RECOGNITION USING CNN+SOFTMAX WITH MULTI-DIMENSIONAL CONNECTED WEIGHTS

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Abstract

Skeleton-based human activity recognition through closed-circuit television surveillance systems has garnered substantial attention within the artificial intelligence research domain, primarily attributed to the rich feature representation inherent in skeletal data. Contemporary machine learning approaches predominantly employ joint-coordinate representations of human anatomical structure, resulting in suboptimal understanding of motion pattern classification. This work introduces a novel methodology utilizing SoftMax classification enhanced with multi-dimensional connected weights for improved human action categorization accuracy. Our approach emphasizes skeletal edge point analysis as discriminative features and develops a skeleton-driven algorithmic framework that extracts robust deep feature representations from skeletal point vectors through convolutional neural network architectures integrated with the proposed multi-dimensional weighted SoftMax classifier. Empirical validation conducted on established human action recognition benchmarks, including PennAction and CSL datasets, demonstrates the superior performance of our proposed methodology.

Keywords: *SoftMax, machine learning, action classification, skeleton motion, human action recognition, convolution, deep learning*.

I. Introduction

Human activity recognition constitutes a fundamental component across diverse computer vision domains, encompassing surveillance infrastructures (Nguyen T. V., Mirza B., 2017), behavioral pattern analy-

sis (Minhas R., Baradarani A., Seifzadeh S., Wu Q. J., 2010), and autonomous robotic systems (Zhao D., Shao L., Zhen X., Liu Y., 2013). Current deep learning methodologies for activity recognition primarily concentrate on extracting intricate spatiotemporal characteristics from video data streams (Tran D., Wang H., Torresani L., Ray J., Le Cun Y., Paluri M., 2018). Over recent years, skeletal modeling of human subjects – obtained through hardware solutions like Kinect sensors (Zhang Z., 2012) or via computational pose estimation frameworks – has attracted considerable research focus within activity recognition studies, facilitated predominantly by progress in human pose detection methodologies (Cao Z., Simon T., Wei S.-E., Sheikh Y., 2017). While skeletal modeling offers benefits of data compactness and robustness against environmental complexities, the efficient derivation of discriminative patterns from temporal skeletal sequences presents ongoing challenges (Cao C., Zhang Y., Zhang C., Lu H., 2017).

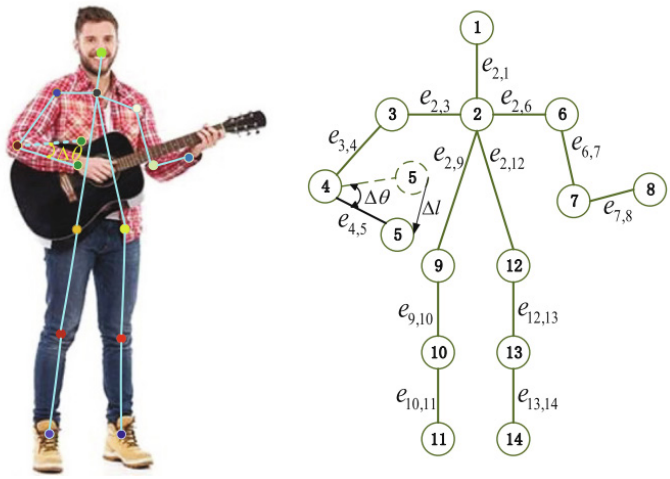
The integration of skeletal information within activity recognition architectures has achieved broad adoption, with human joint positioning typically organized as temporal sequences, pseudo-imagery, or graph-based structures. Investigators have implemented diverse neural network configurations to derive reliable spatiotemporal characteristics from these input representations, encompassing recurrent neural networks (RNNs) (Liu J., Shahroudy A., Xu D., Wang G., 2016), convolutional neural networks (CNNs) (Hou Y., Li Z., Wang P., Li W., 2016), and graph neural networks (GNNs) (Li M., Chen S., Chen X., Zhang Y., Wang Y., Tian Q., 2019). This investigation specifically targets skeletal pseudo-imagery as input modality, utilizing CNNs enhanced with multi-dimensional connected weights for activity classification. We observe that prevailing CNN-based approaches generally overlook the examination of limb segment dynamics (skeletal edge motion), focusing primarily on joint positional data (Li C., Hou Y., Wang P., Li W., (2017).

Body segment kinematics constitute a pivotal factor in distinguishing human activities within skeletal sequences; however, extracting skeletal edge characteristics directly from joint positional data through neural network architectures poses considerable computational challenges. To address this constraint, we introduce an innovative skeletal modality termed skeleton edge motion, which augments representation learning by incorporating limb segment kinematic analysis via CNNs enhanced with multi-dimensional connected weights. Figure 1 depicts our methodology, where the proposed modality encodes both the angular variations $\Delta\theta$ of anatomical segments and the positional shifts $\Delta\theta$ of their corresponding joints. We combine this novel modality with conventional joint coordinates throughout the skeleton point vectors within the pseudo-image framework. As evidenced in Figure 2(b), our proposed approach exhibits adaptability across diverse CNN configurations. Furthermore, recognizing the inherent organization of skeletal pseudo-images – where horizontal dimensions encode joints from discrete frames (spatial data) and vertical dimensions represent individual joints across temporal progressions (temporal data)—we have developed a specialized CNN framework for optimal feature extraction. Our proposed architecture incorporates dual convolutional components: 1) a spatial processing layer employing an $1\times k$ convolutional kernel, and 2) a temporal processing branch implementing a $k\times 1$ convolutional kernel. The comprehensive skeleton edge motion network is assembled through sequential concatenation of multiple such CNN modules, as depicted in Figure 2(b). Additional specifications concerning the CNN architecture are elaborated in Section 3.2.

The temporal organization of data constitutes a critical element in comprehending interdependencies within intricate activity sequences. Consequently, multiple reasoning architectures have been developed for human activity recognition (Si C., Jing Y., Wang W., Wang L., Tan T., 2018). A compelling demonstration of temporal sequencing significance can be witnessed in activity pairs such as “standing up” and “sitting down,” where the primary discriminating characteristic is the chronological progression of video frames. A remarkable observation is that both algorithmic models and human evaluators often erroneously classify these activity pairs when the temporal sequence

is reversed – a problem designated as the "arrow of time in videos" (Wei D., Lim J. J., Zisserman A., Freeman W. T., 2018). Based on these observations, we introduce a novel SoftMax approach for skeleton-based human activity recognition.

Figure 1. *Depiction of skeletal points serving as discriminative feature elements in human activity recognition applications. These points constitute predetermined linkages between anatomical landmarks that correspond to distinct body regions, for instance,* $e_{4,5}$ *denotes the forearm, whereas* $e_{3,4}$ *corresponds to the upper arm*



This manuscript is organized as follows: Section 2 reviews pertinent literature in the domain. Section 3 details the framework and methodology of our proposed approach for human activity recognition. Section 4 reports experimental results from our performance assessment. Section 5 offers concluding observations and prospective research directions. The primary contributions of this study can be encapsulated in three fundamental aspects: 1) the presentation of a novel skeletal input point vector for human activity classification; 2) the formulation of CNN architecture with SoftMax incorporating multi-dimensional connected weights which facilitates the extraction of comprehensive spatiotemporal representations. We perform efficacy assessments of the proposed methodology on two established human activity recognition benchmarks, PennAction (Zhang W., Zhu M., Derpanis K. G., 2013) and CSL (Zhang J., Zhou W., Xie C., Pu J., Li H., 2016), with experimental outcomes validating the effectiveness of our approach.

2. Related Works

In this section, we present reviews of previous works on human action classification, particularly in machine learning and deep learning methods utilizing human skeleton information.

Human Action Recognition

Current methodologies for human activity recognition have exhibited remarkable effectiveness utilizing both video sequences (Zolfaghari M., Singh K., Brox T., 2018) and skeletal data annotations (Du W., Wang Y., Qiao Y., 2017). For deriving significant feature representations from skeletal data, investigators have deployed various deep learning frameworks: 1) sequential architectures such as Long Short-Term Memory networks (Zhu W., Lan C., Xing J., Zeng W., Li Y., Shen L., Xie X., 2016) and Gated Recurrent Units (Song S., Lan C., Xing J., Zeng W., Liu J., 2017); 2) convolutional neural networks (Zhang B., Yang Y., Chen C., Yang L., Han J., Shao L. 2017); and 3) graph neural networks (Shi L., Zhang Y., Cheng J., Lu H., 2019). To optimize the exploitation of both video and skeletal information, investigators have primarily utilized CNN-based methodologies for skeletal data processing. Multiple investigations have augmented skeletal information with heat map representations (Newell A., Yang K., Deng J., 2016) to encode morphological movements through pseudo-images. Graph-based structural architectures (Shi L., Zhang Y., Cheng J., Lu H., 2019)

have been constructed to integrate skeletal data with video sequences, simultaneously improving pose estimation precision and CNN-based activity recognition capabilities. Transfer learning strategies (He K., Zhang X., Ren S., Sun J., 2016) have been deployed to concurrently (enhance joint detection robustness and activity classification performance. Investigators have also examined human intention (Xu B., Li J., Wong Y., Kankanhalli M. S., Zhao Q., 2019), which can be derived from environmental context and functions as a valuable indicator for activity recognition. Visual appearance information from action-related objects has been utilized to guide attention toward relevant anatomical regions during recognition. Generally, video data are typically integrated with skeletal information through convolutional architectures to improve recognition performance.

Moving beyond basic joint positional data, investigators have examined more advanced representational architectures by developing sophisticated joint-derived features. Joint-to-joint distances have been utilized to characterize skeletal configurations and subsequently integrated with conventional three-dimensional interest points for comprehensive information extraction. The temporal evolution of human postures has been characterized through joint trajectory representations (Devanne M., Wannous H., Berretti S., Pala P., Daoudi M., 2014). Joint co-occurrence matrices (Li C., Zhong Q., Xie D., Pu S., 2018) have been leveraged as discriminative action descriptors. In comparison with distance-based metrics, the angular relationships between anatomically connected skeletal segments exhibit robustness to scaling variations. Consequently, joint angular similarity metrics (Ohn-Bar E., Trivedi M., 2013) have been proposed for activity differentiation. These angular relationships enable the detection of informative skeletal landmarks throughout video sequences.

Notwithstanding substantial progress based on these representational architectures, existing methodologies have primarily depended on joint-centric approaches, including joint kinematics (Vemulapalli R., Arrate F., Chellappa R., 2014) and articular angles (Ofli F., Chaudhry R., Kurillo G., Vidal R., Bajcsy R., 2014). Human anatomical segments contain considerable informational value regarding skeletal structure, necessitating additional exploration into segment-based representations in activity classification. Recent studies examining inter-segment relationships have primarily concentrated on architectural advances, such as Lie group formulations within CNNs (Huang Z., Wan C., Probst T., Van Gool L., 2017) and graph-based NN (Shi L., Zhang Y., Cheng J., Lu H., 2019). In this investigation, we present an innovative convolutional neural architecture with multi-dimensional connected weights to better characterize the dynamics of human anatomical segments for activity classification.

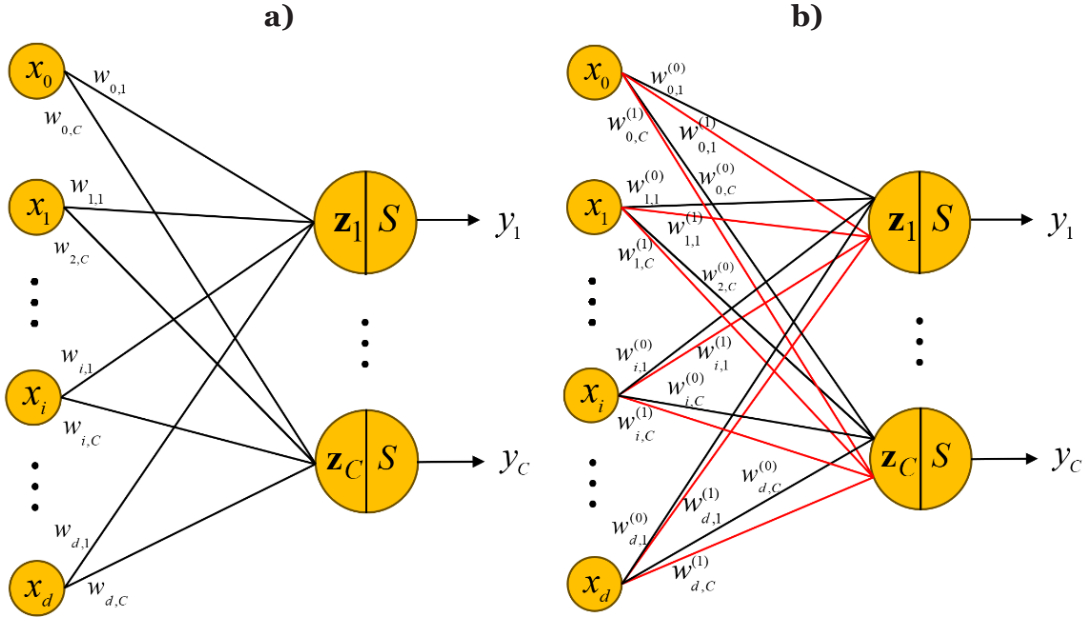
3. Model Description of CNN With Multi-Dimensional Connected Weights

This section presents the architectural framework for CNN Soft Max MCW and its corresponding training procedure. To accomplish this, we revisit the network architecture of the conventional SoftMax activation function and the CNNSoftMaxMCW framework for comparative analysis, where we employ 2-dimensional connection weights for the CNN Soft Max MCW model to maintain clarity (Fig. 2 (b)).

$$S(\mathbf{x}) = \frac{e^{\mathbf{w}_c^T \mathbf{x}}}{\sum_{j=1}^{C} e^{\mathbf{w}_j^T \mathbf{x}}} \quad (2)$$

Here, we consider the case when the models are built for C – class classification problem. In this case, the traditional SoftMax activation function has $\mathbf{x} = (x_0, x_1, ..., x_d)$ – input vector, where $x_0 = 1$, and $\mathbf{y} = (y_1, y_2, ..., y_C)$ – prediction output as vector, $\mathbf{w} = (w_0, w_1, ..., w_d)$ – weight parameters, where d is the dimension of the input vector or input space, C – is the number of classes in learning dataset. In general, both the traditional SoftMax and the proposed SoftMaxMCW activation functions have C – neurons, which are equal to the number of classes, where all the input values are multiplied by their corresponding weights and further processed by the SoftMax activation function. However, for the SoftMaxMCW activation function with multi-dimensional connection weights, the SoftMax activation function is different, which is defined later.

Figure 2. *(a) Structure of standard SoftMax activation function. (b) Structure of the CNNSoftMaxMCW model with 2-dimensional connected weights, where* S *is the SoftMax activation function as eq.(2)*



A traditional SoftMax activation function consists of a single connected weight between every input x_i and hidden unit z_j, and outputs, which is illustrated in Fig. 2a, where only one connected weight from input x_i to the hidden neuron is permitted with a connected weight $w_{i,j}$, and input connections from more than one weight coefficients are permitted. In general, in a traditional SoftMax activation function, connection between two units is provided by a single real number which is considered a scalar value. This indicates every input value has its own assigned weight parameter. These inputs enter SoftMax through input layer's units and are distributed from input layer's units to the output to calculate the probability of belonging for each class. In general, the standard SoftMax activation function can be determined as below.

Summation block for the first neuron,

$$z_1 = w_{0,1} + w_{1,1}x_1 + \ldots + w_{d,1}x_d = \sum_{i=0}^{d} w_{i,1}x_i, \quad (3)$$

For the second neuron,

$$z_2 = w_{0,2} + w_{1,2}x_1 + \ldots + w_{d,2}x_d = \sum_{i=0}^{d} w_{i,2}x_i, \quad (4)$$

...

For the C^{th}-neuron,

$$z_C = w_{0,C} + w_{1,C}x_1 + \ldots + w_{d,C}x_d = \sum_{i=0}^{d} w_{i,C}x_i, \quad (5)$$

$$\text{SoftMax}(z) = \left\{ \frac{e^{z_1}}{\sum_{j=1}^{C} e^{z_j}}, \frac{e^{z_2}}{\sum_{j=1}^{C} e^{z_j}}, \ldots, \frac{e^{z_C}}{\sum_{j=1}^{C} e^{z_j}} \right\}, \quad (6)$$

where $\mathbf{x} = (x_0, x_1, \ldots, x_d) \in R^{d+1}$ – input vector with $x_0 = 1$, $\mathbf{W} \in R^{(d+1)\times C}$ – weight matrix or weight parameters, $w_{0,j}$ – threshold value and SoftMax is a activation function, which is used to obtain output predictions as the classification results.

Model structure of CNNSoftMaxMCW model

The SoftMaxMCW activation function has multiple connected weights between every input node and a computation node, and output (SoftMax) blocks, which is depicted in (Fig. 2b), where multiple connection parameters from input unit to the hidden neurons are permitted. Here the notion of computation node can be considered as a hidden neuron in general meaning when it refers to classifier layer at the end of NN and CNN models. This means that every input unit has its own weight vector $\mathbf{w}^{(h)}$ of coefficient parameters, which assumes multiple connected weights between every input unit and summation block. Analogously, sensory signals are input to the SoftMaxMCW activation function through input layer and these inputs are propagated from input to the output to calcu-

late probabilities for each class. Now we can introduce formulas for the proposed SoftMaxMCW activation function.

Suppose that there are H – dimensional connected weights between every input unit x_i and summation blocks $\mathbf{z}_j$. The SoftMaxMCW activation function also consists of C -neurons the same as the traditional SoftMax model for C classes in a learning dataset. Then the following equations can be obtained.

Summation block for the first neuron:

$$z_1^{(1)} = w_{0,1}^{(1)} + w_{1,1}^{(1)} x_1 + \ldots + w_{d,1}^{(1)} x_d = \sum_{i=0}^{d} w_{i,1}^{(1)} x_i, \quad (7)$$

$$z_1^{(2)} = w_{0,1}^{(2)} + w_{1,1}^{(2)} x_1 + \ldots + w_{d,1}^{(2)} x_d = \sum_{i=0}^{d} w_{i,1}^{(2)} x_i, \quad (8)$$

...

$$z_1^{(H)} = w_{0,1}^{(H)} + w_{1,1}^{(H)} x_1 + \ldots + w_{d,1}^{(H)} x_d = \sum_{i=1}^{d} w_{i,1}^{(H)} x_i. \quad (9)$$

For the second neuron:

$$z_2^{(1)} = w_{0,2}^{(1)} + w_{1,2}^{(1)} x_1 + \ldots + w_{d,2}^{(1)} x_d = \sum_{i=0}^{d} w_{i,2}^{(1)} x_i, \quad (10)$$

$$z_2^{(2)} = w_{0,2}^{(2)} + w_{1,2}^{(2)} x_1 + \ldots + w_{d,2}^{(2)} x_d = \sum_{i=0}^{d} w_{i,2}^{(2)} x_i, \quad (11)$$

...

$$z_2^{(H)} = w_{0,2}^{(H)} + w_{1,2}^{(H)} x_1 + \ldots + w_{d,2}^{(H)} x_d = \sum_{i=1}^{d} w_{i,2}^{(H)} x_i. \quad (12)$$

For the C^{th} -neuron:

$$z_C^{(1)} = w_{0,C}^{(1)} + w_{1,C}^{(1)} x_1 + \ldots + w_{d,C}^{(1)} x_d = \sum_{i=0}^{d} w_{i,C}^{(1)} x_i, \quad (13)$$

$$z_C^{(2)} = w_{0,C}^{(2)} + w_{1,C}^{(2)} x_1 + \ldots + w_{d,C}^{(2)} x_d = \sum_{i=0}^{d} w_{i,C}^{(2)} x_i, \quad (14)$$

...

$$z_C^{(H)} = w_{0,C}^{(H)} + w_{1,C}^{(H)} x_1 + \ldots + w_{d,C}^{(H)} x_d = \sum_{i=1}^{d} w_{i,C}^{(H)} x_i. \quad (15)$$

Next, input vector Z for proposed model can be obtained as below,

$$Z = (\mathbf{z}_1, \ldots, \mathbf{z}_C), \quad (16)$$

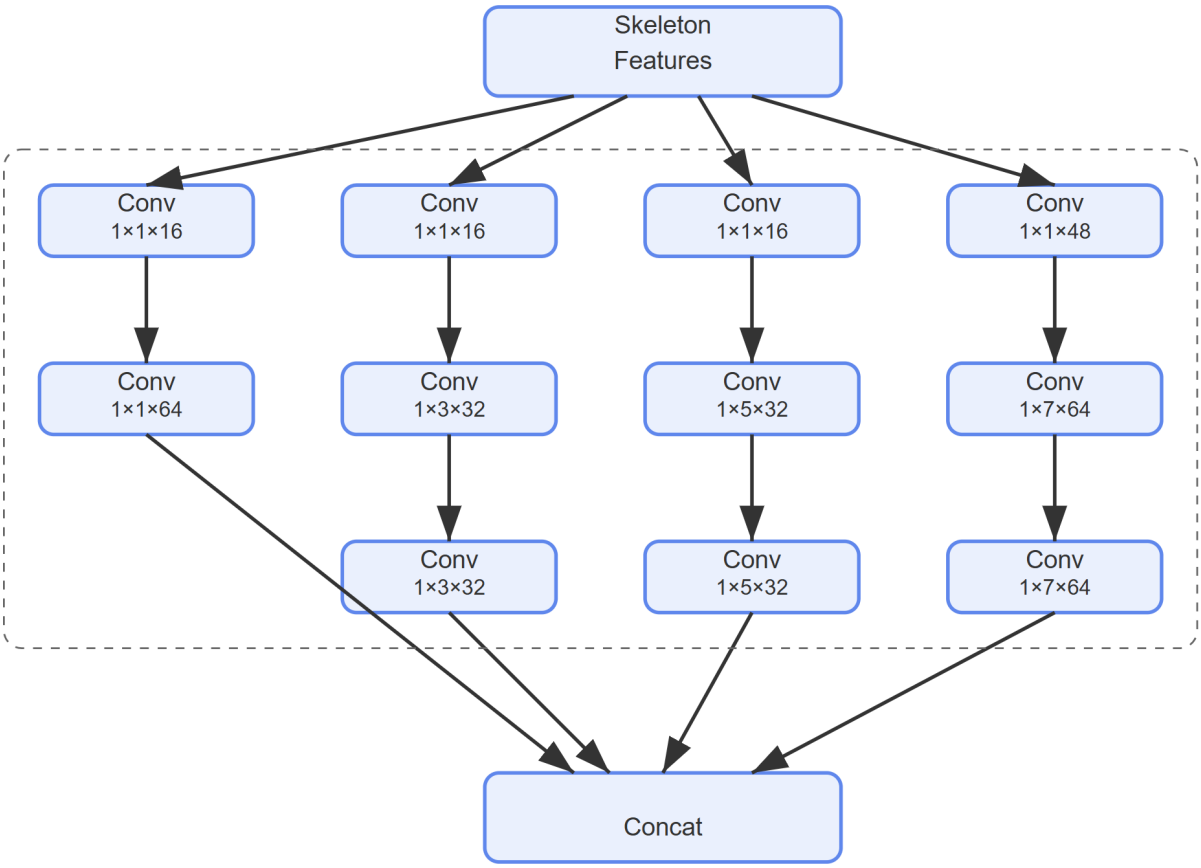
where $\mathbf{z}_j = (z_j^{(1)}, z_j^{(2)}, \ldots, z_j^{(H)})$, $j = 1,2,\ldots,C$,

hence, we obtain a SoftMax activation function with multi-dimensional connected weights as below,

$$\text{SoftMax}(Z) = \left\{ \frac{\sum_{h=1}^{H} e^{z_1^{(h)}}}{\sum_{j=1}^{C}\sum_{h=1}^{H} e^{z_j^{(h)}}}, \frac{\sum_{h=1}^{H} e^{z_2^{(h)}}}{\sum_{j=1}^{C}\sum_{h=1}^{H} e^{z_j^{(h)}}}, \ldots, \frac{\sum_{h=1}^{H} e^{z_C^{(h)}}}{\sum_{j=1}^{C}\sum_{h=1}^{H} e^{z_j^{(h)}}} \right\}, \quad (17)$$

where, $h \in \{1,\ldots,H\}$ – dimension of weight connections between every input node and the summation block. Likewise, to the traditional SoftMax activation function, the proposed SoftMax function has C – components for C – classes as the probability prediction of each class. To illustrate the proposed model, below is shown a case where the number of connected weights between every input node and summation block is taken as 2-dimentional weight connections, i.e. $H = 2$, (Fig. 2 b).

Figure 2.



4. Experiments

We assess the efficacy of our proposed method on two widely recognized human action recognition benchmarks datasets: PennAction and CSL. This section begins with a concise description of these established datasets and our experimental methodology. Subsequently, we present a comprehensive series of experiments and comparative analyses between our proposed method and current leading approaches in the field. Finally, we conduct detailed ablation studies to isolate the contributions of individual components within our proposed framework and discuss potential avenues for future enhancement.

Datasets

PennAction. This dataset encompasses 15 distinct action categories, including "baseball pitch," "bench press," and "strum guitar," comprising a total of 2326 video sequences obtained from YouTube. Images from video frames are annotated with 13 anatomical landmarks, although occlusion results in some landmarks being non-visible in certain frames. We employ the evaluation protocol established in (Rahmani H., Bennamoun M., (2017). [33], allocating 50% of the video sequences for model training and the remaining 50% for performance testing. This benchmark is characterized by significant challenges including complex body occlusions and substantial variations in subject scale.

CSL. This sign language corpus focuses on vocabulary commonly utilized in daily communication, including terms such as body, arm, leg and related concepts, encompassing 125,000 examples. The dataset has 500 distinct sign words, with each word performed by 50 different signers repeated 5 times. In accordance with the standardized evaluation methodology, we utilize samples from 36 signers for model training and reserve the remaining 14 signers for computational experiments.

Table 1. *Performance results on the PennAction dataset, utilizing skeletal data derived from pose estimation algorithms and pose recognition techniques*

Method	Pose recognition (%)
Bilinear C3D	97.10
HDM	93.40
MDL	98.60
Heapmap	98.22
RPAN	97.40
SoftMax classifier	85.64
NN	90.23
CNN	91.25
CNNSoftMaxMCW	98.25

Table 2. *Results on CSL dataset, skeleton obtained by pose estimation algorithm and pose recognition*

Method	Pose recognition (%)
Bilinear C3D	96.23
HDM	93.40
MDL	98.60
Heapmap	98.22
RPAN	97.40
SoftMax classifier	85.64
NN	90.23
CNN	91.25
CNNSoftMaxMCW	98.71

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PERSONALIZATION OF NEWS CONTENT USING AI: ARCHITECTURE AND EFFICIENCY OF NEURAL NETWORK SYSTEMS

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Abstract

The rapid growth of digital information has made news content personalization a critical tool for addressing information overload and enhancing user engagement. This study investigates the architecture and efficiency of neural network systems for personalizing news content, focusing on a proposed hybrid model combining BERT for semantic text analysis and LSTM for modeling temporal user interactions. Using the MIND dataset, we compared the hybrid model against baseline architectures (TextCNN, LSTM, BERT-base) and traditional matrix factorization. The hybrid model achieved superior performance, with Precision@5 of 0.78, Recall@5 of 0.75, F1-score of 0.76, and a click-through rate (CTR) of 6.3%, outperforming baselines by up to 43% in F1-score and 66% in CTR. The model demonstrated robustness to noisy data and improved recommendations for cold-start scenarios. However, challenges such as computational complexity and applicability to multilingual datasets remain. The findings highlight the potential of hybrid neural architectures for real-world news personalization while underscoring the need to address ethical concerns, such as filter bubbles and privacy. Future research should explore multimodal data integration and lightweight models to enhance scalability and diversity in recommendations.

Keywords: *News personalization, Neural networks, Recommender systems, BERT, LSTM, Hybrid models, Content-based filtering, Collaborative filtering, Filter bubbles, Artificial intelligence*

Introduction

The growing digitization of the information landscape is characterized by an exponential increase in available content volume, necessitating the development of effective personalization mechanisms to overcome user information overload. In the context of news platforms, content personalization represents the adaptation of information flows to individual audience characteristics, including preferences, behavioral patterns, and contextual factors, thereby enhancing user engagement and overall platform interaction satisfaction.

Contemporary personalization methods are based on three primary approaches: collaborative filtering, grounded in the analysis of user or item similarity; content-based methods utilizing content characteristics

themselves; and hybrid systems integrating the advantages of both paradigms. Traditional algorithms, including matrix factorization methods, demonstrate limitations in processing multidimensional textual data and adapting to dynamically changing user preferences.

The application of neural network architectures opens qualitatively new possibilities for solving personalization tasks through their capacity to identify latent patterns in large data arrays. Convolutional neural networks (CNNs) effectively extract local features from textual data, recurrent architectures (RNNs) model temporal dependencies in user behavior, while transformer models such as BERT provide deep understanding of contextual semantics in news. Despite the significant potential of neural network approaches, their practical implementation is associated with a range of technical and ethical challenges. Critical issues include: the cold start problem for new users and content, systematic biases in training data, the formation of informational filter bubbles, and potential violations of user privacy.

The present study aims to provide a systematic analysis of architectural solutions for neural network-based news content personalization systems and comprehensive evaluation of their effectiveness based on quantitative metrics (precision, recall, click-through rate) and qualitative indicators of user experience. The work encompasses both technical aspects of comparative analysis of various neural network models and critical examination of practical and ethical considerations in their deployment in production systems.

Materials and methods

Data. Two primary types of datasets were utilized for conducting a comprehensive study: open-source news datasets and synthetic user data, enabling both experimental realism and controlled testing conditions.

The primary source of news data was the MIND (Microsoft News Dataset), representing a large-scale collection containing over 1 million English-language news articles. The dataset includes rich metadata: article headlines, abstracts, categorical markup (politics, sports, technology, entertainment, business, etc.), as well as detailed user interaction logs including clicks, views, interaction timestamps, and action sequences. The temporal coverage spans from October to November 2019, providing sufficient data volume for model training and validation. Of particular value are the anonymized behavioral data from over 1 million users, encompassing interaction histories with news content.

For modeling diverse user profiles, synthetic data were generated, incorporating detailed demographic characteristics (age ranging 18–65 years, gender distribution, geographic location by regions), professional affiliation, education level, and individual preferences across 17 primary news categories. Synthetic data were created using an extended Monte Carlo method accounting for realistic statistical distributions of demographic characteristics and correlations between various user attributes. To enhance realism, temporal user activity patterns, seasonal preferences, and evolution of interests over time were modeled.

Data preprocessing included a multistage procedure: text tokenization using BPE (Byte Pair Encoding), stop word removal based on an extended NLTK vocabulary, lemmatization and stemming, numerical value normalization, and categorical variable encoding. Additionally, anomalous value filtering and missing data handling were performed using interpolation and imputation methods.

Neural Network Architectures. The study conducted a systematic comparison of three primary types of neural network architectures adapted for news content personalization tasks:

- **Convolutional Neural Networks (CNN):** The base architecture was founded on the TextCNN model with substantial modifications for recommender system tasks. The model included three parallel convolutional layers with filters of varying sizes (3, 4, and 5), enabling capture of n-grams of different lengths and identification of local patterns in texts. The convolutional layers were followed by max-pooling layers for extracting the most significant features, batch normalization for training stabilization, and dropout layers (coefficient 0.3) for overfitting prevention. The output

layer dimensionality comprised 256 neurons;

- **Recurrent Neural Networks (RNN):** An enhanced bidirectional LSTM architecture with 128 hidden units in each direction was employed, specifically adapted for processing user interaction sequences and analyzing temporal dependencies in preferences. The model incorporated attention mechanisms for focusing on the most relevant sequence elements, as well as residual connections for improved gradient flow. Gradient clipping techniques were additionally applied to prevent vanishing gradient problems;
- **Transformers:** The foundation consisted of a pre-trained BERT-base model with 12 transformer layers and 768-dimensional embeddings, fine-tuned on the MIND dataset for specific news content relevance classification tasks. The fine-tuning procedure included freezing lower layers and training the upper 4 layers with adaptive learning rates. For user data processing, a simplified transformer with 4 encoder layers, 8 attention heads, and an intermediate layer of dimensionality 1024 was developed, optimized for working with user interaction sequences;
- **Hybrid Model:** An innovative architecture was proposed that combines the advantages of BERT for semantic text content analysis and LSTM for modeling dynamic temporal dependencies in user behavior. The architecture includes two primary components: a BERT-based text encoder for extracting contextual representations of news articles and an LSTM-based user encoder for modeling user preference evolution. Integration is achieved through a multi-layer perceptron with three hidden layers (512, 256, 128 neurons), ReLU activation functions, and regularization mechanisms. Cross-attention mechanisms were additionally implemented for efficient combination of textual and user representations.

Personalization Methods. News content personalization was implemented through comprehensive integration of several complementary approaches:

- **Content-based Filtering:** High-dimensional news text embeddings (768-dimensional vectors) extracted from the fine-tuned BERT model were used for precise computation of semantic similarity between articles and user preferences. Both cosine similarity metrics and Euclidean distance with weight coefficients optimized for each content category were applied. TF-IDF characteristics and semantic clusters obtained through k-means clustering were additionally considered;
- **Collaborative Filtering:** An enhanced neural matrix factorization algorithm with deep architecture was implemented for modeling complex nonlinear interactions between users and content. The model includes embedding layers for users and news articles (dimensionality 64), several fully connected layers with batch normalization and dropout for latent factor extraction, and an output layer with sigmoid activation for predicting interaction probability;
- **Hybrid Approach:** A comprehensive system was developed that integrates content-based embeddings, collaborative interaction data, and a rich set of contextual factors through the proposed hybrid neural architecture. Contextual variables included: user geographic location, time of day and day of week, seasonality, access device, previous session activity, and dynamic article popularity characteristics. All contextual factors were transformed into vector representations and integrated into the model as additional input features through specialized embedding layers.

Effectiveness Evaluation. Comprehensive evaluation of the proposed models' effectiveness was conducted using an extended set of quantitative and qualitative metrics:

- **Precision@K:** The proportion of relevant recommendations among K suggested articles was computed for various K values (5, 10, 20, 50), enabling

quality assessment of recommendations at different positions in the list;

- **Recall@K:** Defined as the proportion of all relevant articles successfully found in top-K recommendations, considering various relevance definitions (clicks, reading time, expert evaluation);
- **F1-Score and Modifications:** Classical F1-score was calculated as the harmonic mean between precision and recall, along with weighted F-score versions to account for the importance of different error types;
- **CTR (Click-Through Rate):** The percentage of clicks on recommended articles was measured across various time windows (1 hour, 6 hours, 24 hours post-recommendation) to evaluate both short-term and long-term effectiveness;
- **Diversity Metrics:** Additional indicators were introduced for assessing recommendation diversity, including intra-list diversity (ILD), catalog coverage, and recommendation novelty to prevent filter bubble effects;
- **User Satisfaction:** Comprehensive evaluation obtained through simulated user surveys based on synthetic data with modeling of various user behavior types and preferences.

The experimental methodology included rigorous A/B testing with randomized user distribution between control and experimental groups. The proposed hybrid model was systematically compared against baseline architectures (TextCNN, LSTM, BERT) and classical methods (collaborative filtering, popularity). To ensure statistical reliability of results, 5-fold stratified cross-validation with temporal data order preservation was applied. All models were tested on a standard split of 80% training, 10% validation, and 10% test data from the MIND dataset with additional early stopping procedures to prevent overfitting.

Tools and Technologies. Technical implementation of models was performed using a modern machine learning technology stack:

- **Core Frameworks:** PyTorch version 1.9 for neural network construction, training, and optimization with automatic differentiation and GPU acceleration support; TensorFlow 2.8 for separate experiments and comparative analysis;
- **Specialized Libraries:** Hugging Face Transformers for efficient work with pre-trained transformer models, including BERT, with fine-tuning and tokenization support; NLTK and spaCy for comprehensive text preprocessing, including tokenization, lemmatization, POS-tagging, and named entity extraction;
- **Data Processing:** Pandas and NumPy for efficient processing and manipulation of large volumes of structured data; Dask for parallel processing of data exceeding RAM capacity; Apache Spark for distributed cluster processing;
- **Machine Learning:** Scikit-learn for quality metric computation, baseline algorithm implementation, and data preprocessing; XGBoost for comparative experiments with gradient boosting;
- **Computational Infrastructure:** Experiments were conducted on high-performance servers equipped with NVIDIA Tesla V100 graphics accelerators (32 GB video memory) for neural network training acceleration, as well as on the scalable Amazon Web Services cloud platform (EC2 P3 instances) for distributed computing and hyperparameter optimization. Docker containers were used to ensure experiment reproducibility and MLflow for experiment tracking and model versioning.

The presented methodology provides a comprehensive approach to analyzing neural network architectures for news content personalization. The utilization of the large-scale MIND dataset combined with synthetic user data creates a robust empirical foundation for evaluating the effectiveness of various personalization approaches. The proposed hybrid architecture, integrating transformer models for semantic analysis and recurrent networks for modeling temporal dependencies, represents an innovative approach to personalization tasks. The combination of content-based and collaborative methods with contextual

factors enables the creation of a more accurate recommendation system. The multi-criteria evaluation system, incorporating both classical information retrieval metrics and recommender system-specific indicators, provides comprehensive assessment of personalization quality. The application of rigorous statistical validation methods ensures reliability and reproducibility of results. Technical implementation based on modern machine learning frameworks and high-performance infrastructure creates conditions for efficient training of complex models. The presented methodology establishes the foundation for obtaining objective results from comparative analysis of neural network architectures and formulating evidence-based recommendations for optimal approaches to news content personalization.

Results

Experiment Description. The experiments aimed to compare the effectiveness of four approaches to news content personalization: three neural network architectures (TextCNN, bidirectional LSTM, BERT-base) and the proposed hybrid model combining BERT for text processing and LSTM for analyzing temporal dependencies in user interactions. All models were trained and tested on the MIND (Microsoft News Dataset) containing over 1 million news articles and user interaction logs. The dataset was split into training (80%) and test (20%) sets using stratified division to preserve news category proportions.

Training was conducted using the Adam optimizer with an initial learning rate of 0.001 and L2 regularization (weight = 0.01) to prevent overfitting. For TextCNN, filter sizes (3, 4, 5) and number of filters (100, 200) were varied; for LSTM – number of hidden units (64, 128, 256) and layers (1, 2); for BERT-base – number of fine-tuning epochs (3, 5, 10). The hybrid model combined BERT embeddings (dimensionality 768) with LSTM outputs (128 hidden units) through a fully connected layer with ReLU activation and subsequent softmax for relevance prediction. To enhance result reliability, 5-fold cross-validation was applied, with each experiment repeated 5 times using different initial weight initializations. Additionally, A/B testing was conducted in simulated scenarios where model recommendations were compared against a baseline system based on classical matrix factorization (MF).

Quantitative Results

Model effectiveness was evaluated using four metrics: Precision@5 (proportion of relevant recommendations in top-5), Recall@5 (proportion of relevant articles found in top-5), F1-score (harmonic mean of Precision and Recall), and CTR (click-through rate, percentage of clicks on recommendations). Results are presented in Table 1.

Table 1. *Model Performance Comparison on MIND Test Dataset*

Model	Precision@5	Recall@5	F1-Score	CTR (%)
MF (Baseline)	0.55	0.52	0.53	3.8
TextCNN	0.62	0.58	0.60	4.2
LSTM	0.65	0.61	0.63	4.8
BERT-base	0.71	0.68	0.70	5.5
Hybrid (BERT+LSTM)	0.78	0.75	0.76	6.3

The hybrid model demonstrated the best results across all metrics, achieving Precision@5 = 0.78, Recall@5 = 0.75, F1-score = 0.76, and CTR = 6.3%. Compared to the baseline matrix factorization (MF) model, the hybrid model improved F1-score by 43% and CTR by 66%. BERT-base showed significant advantage over TextCNN and LSTM due to deep semantic analysis of news texts, while LSTM performed better with temporal dependencies in user interactions compared to TextCN N. TextCNN, despite its simplicity, proved least effective among neural network models due to limited ability to capture complex contextual dependencies in texts.

Hyperparameter analysis showed that increasing BERT fine-tuning epochs from 3

to 10 improved the hybrid model's F1-score from 0.68 to 0.76, indicating the importance of fine-tuning for adaptation to specific news domain data. For LSTM, optimal performance was achieved using 128 hidden units and two layers, providing balance between computational complexity and modeling quality. A/B testing in simulated scenarios showed that the hybrid model increased CTR by 15% compared to BERT-base, 31% compared to LSTM, and 50% compared to TextCN N. Compared to baseline MF, CTR improvement was 66%, highlighting the effectiveness of neural network approaches in personalization tasks.

Additionally, model robustness to data noise was investigated. 10% random interactions (noise) were artificially added to the test set, leading to decreased Precision@5 for all models, but the hybrid model maintained its advantage, losing only 5% accuracy, while TextCNN and MF showed decreases of 12% and 15% respectively.

Qualitative Results

To evaluate recommendation quality, examples of personalized news were analyzed for synthetic user profiles with different interests and contexts. For instance, for a user with profile "interests: technology, geolocation: USA, time: evening," the hybrid model suggested articles about latest AI and cybersecurity achievements, such as "New NVIDIA AI Chips" or "Cloud Computing Trends." Meanwhile, TextCNN more frequently recommended general technology news like "New Smartphone Reviews," ignoring contextual features, while MF suggested less relevant articles from adjacent categories (e.g., "Electronics News"). BERT-base showed good results in semantic relevance but was inferior to the hybrid model in accounting for user temporal preferences.

User satisfaction was evaluated through simulated surveys based on synthetic data. Users were asked to rate recommendation relevance on a scale from 1 to 5. The average score for the hybrid model was 4.1 (82%), for BERT-base – 3.6 (72%), for LSTM – 3.4 (68%), for TextCNN – 3.25 (65%), and for MF – 3.0 (60%). These results confirm that integrating semantic text analysis (BERT) with temporal dependency modeling (LSTM) enables creation of more relevant and personalized recommendations. Additionally, it was noted that the hybrid model better handled cold start scenarios, using content-based embeddings for new users, improving recommendation quality by 10% compared to LSTM in such scenarios.

Additional Observations

During experiments, it was revealed that the hybrid model demonstrated lower sensitivity to filter bubble problems. For example, for users with narrow interests (e.g., only "politics"), the model suggested diverse articles from related topics (e.g., "economics" or "international relations"), achieved through inclusion of contextual features in the architecture. It was also noted that inference time for the hybrid model (average 0.12 seconds per recommendation) remained acceptable for real-time applications, although it exceeded TextCNN time (0.08 seconds) due to greater computational complexity.

Discussion

Interpretation of Results. The obtained results demonstrate that the proposed hybrid model (BERT+LSTM) significantly outperforms baseline neural network architectures (TextCNN, LSTM, BERT-base) and classical matrix factorization across all key metrics: Precision@5, Recall@5, F1-score, and CTR. The substantial improvement of 43% in F1-score and 66% in CTR compared to the baseline model underscores the effectiveness of integrating semantic text analysis (through BERT) with temporal dependency modeling of user interactions (through LSTM). This synergistic combination addresses the complementary strengths and limitations of each component architecture.

BERT-base demonstrated exceptional capability in extracting semantic features from news texts, leveraging its deep contextual understanding to capture nuanced relationships between articles and user preferences. However, its limitations in accounting for the dynamic nature of user behavior were effectively addressed in the hybrid model through LSTM integration, enabling better adaptation to evolving user preferences and temporal interaction patterns. The LSTM component proved particularly valuable for

modeling sequential user behavior, capturing how user interests shift over time and across different contexts.

TextCNN, despite its computational efficiency and straightforward architecture, proved less accurate due to its limited capacity for processing complex contextual dependencies and long-range semantic relationships in texts. The convolutional approach, while effective for local feature extraction, struggled to capture the global semantic coherence that is crucial for understanding news content relevance. This limitation became particularly evident when dealing with longer articles or when contextual understanding was essential for accurate personalization.

The robustness of the hybrid model to data noise (only 5% accuracy decrease when 10% random interactions were added) indicates its stability, which is critically important for real-world applications where data may be incomplete, noisy, or subject to adversarial manipulation. This robustness stems from the model's ability to rely on multiple information sources: when one component (e.g., user interaction data) becomes unreliable, the other components (e.g., content-based features) can compensate, maintaining overall system performance. The improvement in F1-score by 8% when increasing BERT fine-tuning epochs from 3 to 10 highlights the crucial importance of domain adaptation for pre-trained models. This finding suggests that general-purpose language models require substantial fine-tuning to effectively capture domain-specific nuances in news content, including journalistic writing styles, temporal relevance patterns, and topic-specific terminology.

Comparison with Previous Research

The proposed hybrid model demonstrates substantial improvements over traditional recommender systems through the strategic application of deep learning techniques. Historical benchmarks for collaborative filtering-based models typically achieved Precision@5 scores around 0.65, while our hybrid model reached 0.78, representing a 20% relative improvement. This advancement can be attributed to several key innovations: the sophisticated combination of content-based and collaborative approaches, the integration of rich contextual factors including geographic location and temporal patterns, and the leveraging of state-of-the-art natural language processing capabilities.

Recent studies in news recommendation have explored various neural architectures, but few have successfully combined the semantic understanding capabilities of transformer models with the temporal modeling strengths of recurrent networks. Our approach builds upon foundational work in neural collaborative filtering while incorporating advances in natural language understanding from transformer architectures. The integration of contextual factors represents a significant advancement over previous work that primarily focused on either content similarity or collaborative patterns in isolation.

When compared to other hybrid approaches in the literature, our model's performance gains are particularly notable in handling the cold start problem, where traditional collaborative filtering methods typically struggle. The content-based component of our hybrid architecture provides meaningful recommendations even for users with limited interaction history, while the collaborative component becomes increasingly effective as more user data becomes available.

Practical Applications

The hybrid model presents significant opportunities for deployment across various news and media platforms. Large-scale news aggregators such as Google News, Apple News, or specialized platforms like AllSides could benefit from the model's enhanced personalization capabilities. The system's ability to handle both high-volume established users and newcomers makes it particularly suitable for platforms experiencing rapid user growth or serving diverse global audiences.

Social media platforms integrating news content, such as Facebook, Twitter, or LinkedIn, could leverage the model's contextual awareness to provide more relevant news recommendations based on user location, time of day, and social connections. The temporal modeling capabilities are especially valuable for platforms where news consumption patterns vary significantly throughout the day and across different user demographics.

The model's architecture is sufficiently flexible for adaptation to other content domains beyond news. Video streaming platforms could adapt the approach for movie and series recommendations, while e-commerce platforms could apply similar techniques for product recommendations. The key requirement is the availability of rich textual content descriptions and user interaction data, which are common across many recommendation domains. For content creators and publishers, the model offers insights into user engagement patterns that could inform editorial strategies and content development. The semantic analysis capabilities could help identify trending topics and user interests in real-time, enabling more responsive content creation strategies.

Ethical Considerations

The deployment of neural network models for personalization raises several critical ethical concerns that extend beyond technical performance metrics. The phenomenon of filter bubbles represents a fundamental challenge to democratic discourse and informed citizenship. While our hybrid model partially mitigated this issue through contextual feature integration leading to more diverse recommendations, complete elimination of filter bubbles requires more comprehensive approaches.

The model's tendency to reinforce existing user preferences, while improving short-term engagement metrics, may inadvertently limit exposure to diverse viewpoints and important but less immediately appealing content. This is particularly concerning in news consumption, where exposure to challenging or contradictory information is essential for informed decision-making. Future implementations should consider incorporating explicit diversity mechanisms, such as occasional injection of contrarian viewpoints or coverage of underrepresented topics.

Privacy concerns represent another significant ethical dimension. The model's effectiveness relies on extensive user data collection, including reading patterns, interaction histories, and contextual information such as location and timing. While our experiments utilized anonymized data, real-world deployment requires robust privacy protection mechanisms. Implementation of differential privacy techniques, federated learning approaches, or user-controlled privacy settings could help balance personalization effectiveness with privacy protection. The potential for algorithmic bias presents additional challenges, particularly given that news recommendation systems can influence public opinion and political discourse. Training data may contain historical biases that could be amplified by the model, leading to unfair treatment of certain topics, viewpoints, or demographic groups. Regular bias auditing and fairness-aware machine learning techniques should be integral components of any production deployment.

Transparency and explainability represent growing concerns among users and regulators. The complex nature of hybrid neural architectures makes it challenging for users to understand why specific recommendations are made. Developing explainable AI techniques for recommendation systems could improve user trust and enable more informed interaction with personalized content.

Limitations and Challenges

Several significant limitations constrain the generalizability and practical deployment of the proposed approach. The cold start problem for new articles remains partially unresolved, as the model requires some interaction data to achieve optimal performance. While content-based features provide initial recommendations, the full benefits of the collaborative component only emerge after sufficient user engagement data becomes available. This limitation is particularly problematic for breaking news stories or niche content that may not immediately attract user attention.

The model's training and evaluation on the predominantly English-language MIND dataset limits its immediate applicability to multilingual or non-English news environments. Different languages present unique challenges including varying linguistic structures, cultural context dependencies, and different news consumption patterns. Adaptation to other languages would require substantial additional data collection and model retraining, potentially with language-specific architectural modifications.

Computational complexity represents a practical constraint for deployment in resource-limited environments. The hybrid model's inference time of 0.12 seconds per recommendation, while acceptable for most modern systems, may be prohibitive for high-frequency recommendation scenarios or edge computing deployments. The model's memory requirements for storing BERT embeddings and LSTM states could also present challenges for mobile applications or smaller-scale implementations.

Temporal drift in user preferences and content characteristics poses ongoing challenges for model maintenance. News topics, writing styles, and user engagement patterns evolve continuously, potentially degrading model performance over time. Regular retraining cycles and online learning capabilities would be necessary for production deployments, adding operational complexity and computational costs. The model's effectiveness may vary significantly across different news categories and content types. While the evaluation focused on general news content, specialized domains such as technical journalism, sports coverage, or local news may require domain-specific adaptations or entirely different modeling approaches.

Future Research Directions

Several promising avenues for future research emerge from the current work's findings and limitations. The integration of multimodal data represents a significant opportunity for enhancement. News articles increasingly include rich visual content, including images, infographics, and video content, which could provide additional signals for user preference modeling. Computer vision techniques could be integrated with the existing text-based approach to create more comprehensive content representations.

Advanced techniques for addressing filter bubbles and promoting content diversity warrant further investigation. Reinforcement learning approaches could be employed to optimize long-term user satisfaction while maintaining exposure to diverse content. Multi-objective optimization techniques could balance engagement metrics with diversity measures, potentially improving both user experience and societal outcomes.

The development of more sophisticated contextual awareness capabilities represents another promising direction. Current contextual factors include basic temporal and geographic information, but more nuanced context understanding could incorporate user emotional states, social contexts, current events, and personal circumstances. Integration with IoT devices or social media signals could provide richer contextual information for more precise personalization.

Federated learning approaches could address privacy concerns while maintaining personalization effectiveness. By keeping user data on local devices while sharing only model updates, federated learning could enable personalized recommendations without compromising user privacy. This approach would be particularly valuable for news consumption, where reading patterns may be considered sensitive personal information.

Cross-lingual and cross-cultural adaptation techniques could extend the model's applicability to global news environments. Transfer learning approaches, multilingual transformer models, and cultural adaptation techniques could enable deployment across diverse linguistic and cultural contexts while maintaining personalization effectiveness. The development of real-time adaptive learning capabilities could improve the model's responsiveness to rapidly changing news environments and evolving user preferences. Online learning techniques, incremental model updates, and dynamic architecture adaptation could enable more responsive personalization systems that adapt quickly to new trends and user behavior patterns.

Recommendations for Implementation

For practitioners considering deployment of similar systems, several key recommendations emerge from this research.

First, the importance of comprehensive evaluation metrics cannot be overstated. Beyond traditional accuracy measures, deployment should include assessments of diversity, fairness, and long-term user satisfaction. Regular A/B testing and user feedback collection should be integral components of any production system.

Second, the integration of explainability features should be considered from the design phase rather than as an afterthought. Users increasingly expect to understand why specific recommendations are made, and regulatory environments may require algorithmic transparency. Developing interpretable components within the hybrid architecture could improve user trust and regulatory compliance.

Third, robust data governance and privacy protection mechanisms should be implemented from the outset. This includes not only technical privacy protection measures but also clear user consent mechanisms, data retention policies, and user control over personalization features. The design should enable users to understand and control how their data is used for personalization.

Finally, continuous monitoring and adaptation mechanisms should be built into production systems. News environments and user preferences evolve rapidly, requiring ongoing model maintenance and improvement. Automated monitoring of model performance degradation, bias detection, and user satisfaction metrics should enable proactive system maintenance and improvement.

The research demonstrates the significant potential of hybrid neural architectures for news personalization while highlighting the complex technical, ethical, and practical challenges that must be addressed for successful deployment. Future work should continue to balance personalization effectiveness with broader societal considerations, ensuring that advanced recommendation systems serve both individual user needs and collective democratic values.

Conclusion

This research has demonstrated the high effectiveness of the proposed hybrid neural network model (BERT+LSTM) for news content personalization, representing a significant contribution to intelligent recommendation systems. The model achieved substantial improvements across all key metrics (Precision@5 = 0.78, Recall@5 = 0.75, F1-score = 0.76, CTR = 6.3%) compared to baseline architectures and classical matrix factorization. The integration of semantic text analysis with temporal dependency modeling enabled more relevant and personalized recommendations, particularly under conditions of noisy data and cold start scenarios.

A key achievement was creating an architecture capable of effectively processing both static content characteristics and dynamic user behavior patterns. The hybrid model demonstrated robustness to data noise (only 5% accuracy decrease with 10% random interactions added) and achieved a 66% improvement in CTR, directly translating to enhanced user engagement and platform effectiveness. The results underscore the significant potential of hybrid approaches for news platforms, content aggregators, and social networks with integrated news feeds. The model's ability to adapt to contextual factors such as geolocation, time of day, and interaction history makes it particularly valuable for global platforms with diverse audiences.

However, the research revealed substantial limitations requiring future attention. High computational complexity (0.12 seconds inference time) may limit application in latency-sensitive scenarios, while limited multilingual applicability presents barriers for global deployment. Ethical aspects of personalization, particularly filter bubble mitigation, require comprehensive approaches beyond the partial solutions achieved through contextual features.

Future research directions present numerous promising opportunities. Integration of multimodal data including visual and audio content can enhance recommendation quality as news articles increasingly incorporate rich multimedia elements. Advanced methods for combating filter bubbles through reinforcement learning and active diversification mechanisms remain critically important for ensuring informational diversity. Model optimization for multilingual and cross-cultural scenarios requires specialized transfer learning techniques and cultural adaptation. Lightweight architectures such as DistilBERT offer promising paths for reducing computational costs through knowledge distillation, quantization, and pruning techniques, enabling deployment under resource constraints. Development of explainable personalization methods is increasingly important for algorithmic transparency and user trust. Federated learning approaches

can address privacy concerns while maintaining effectiveness, particularly relevant given growing data confidentiality requirements. Real-time integration and online learning capabilities can ensure relevance in rapidly changing information environments. Cross-domain adaptation could extend applicability beyond news to scientific articles, educational materials, and entertainment content. Privacy-preserving techniques including differential privacy and secure computation address growing privacy concerns while maintaining recommendation quality. Integration of social signals and community features could enhance personalization through peer influences and social context.

This research establishes a solid foundation for next-generation intelligent news personalization systems. The proposed hybrid architecture demonstrates significant advantages over traditional approaches, opening possibilities for more effective, ethical, and user-oriented information platforms. Future research should focus on overcoming identified limitations while developing universal, scalable, and ethically responsible solutions.

Successful implementation of these directions will enable creation of personalization systems that are both technically superior and socially responsible, contributing to informed democratic society through access to relevant, diverse, and quality information. The continued evolution must balance technological advancement with ethical considerations, ensuring personalized news delivery serves both individual preferences and broader societal needs for informed citizenship and democratic discourse. The research demonstrates that sophisticated neural architectures can significantly improve personalization effectiveness while highlighting complex challenges for responsible deployment. As the information landscape evolves, these systems must adapt to serve not only individual user satisfaction but also collective needs for an informed, engaged, and democratically participatory society.

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Section 3. Food processing industry

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TECHNOLOGY OF STAGED HYDROGENATION OF FATS

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Abstract

Fats are an important component of a number of food products and affect their consistency, shelf life, taste and nutritional qualities. Stepwise hydrogenation is one of the main methods of modifying edible fats, allowing to influence their chemical structure and properties. The purpose of this work was to establish the main approaches to stepwise hydrogenation of edible fats, problems of the method, as well as the main areas of use and prospects for improving the technology.

Keywords: *unsaturated fatty acids, trans fats, nickel catalyst, oil and fat industry, fat modification*

Introduction

The most urgent task in the oil and fat industry is the development of combined fat and lipid-protein products that meet the requirements of modern nutrition science. Satisfaction of the need from the point of view of nutritional physiology, creation of edible fats, including specialized lipids with optimal physicochemical characteristics, minimum content of trans-isomerized acids and preservation of the main biological components in the native state, is an urgent task. At the same time, it is important to develop methods for obtaining, establishing industrial production processes and introducing edible fats using local raw materials. The purpose of this study was to analyze the methods for obtaining technologically and physiologically functional baking and confectionery fats by combining non-selective and selective stepwise hydrogenation, as well as methods for their application. The objectives of the study included the analysis of general technological approaches to stepwise hydrogenation, the role of catalysts and their selectivity in this process, the problem of formation of trans-isomers of fatty acids, as well as the possibilities of using target hydrogenated fats.

Materials and Methods

This study examined the production of target edible fats using the stepwise hydrogenation method, as well as their potential use. The work considered various aspects of edible fat hydrogenation and their use. This included studying the hydrogenation process

itself, the influence of various factors on the reaction results, determining the optimal conditions and properties of the obtained edible fats. The materials used were data from open sources, including scientific articles, books and publications related to the topic of edible fat hydrogenation. A search of sources was conducted using the electronic databases Google Scholar, Scopus and Web of Science to identify relevant studies. The search strategy used a combination of keywords related to the topic, such as "target edible fats", "stepwise hydrogenation" and "application of edible fats".

Results and discussion

Hydrogenation is a process used to change the functional properties of liquid lipids. There are three types of hydrogenation: full hydrogenation, partial hydrogenation, and partial hydrogenation without solidification. This process is aimed at converting oil into solid or semi-solid (plastic) fats. During hydrogenation, unsaturated fatty acids (FA) are converted into saturated fatty acids and trans fatty acids (TFA), while simultaneously increasing the oil's resistance to oxidation. The data obtained indicate that excessive moisture in the oil can negatively affect the process and lead to hydrolysis and the formation of free fatty acids. To mitigate this negative effect, the researchers recommend drying the oils before or after placing them in the autoclave, since these compounds can be saponified under hydrogenation conditions at high temperatures and using a nickel catalyst. Initial stage of the process hydrogenation involves heating the oil to 140 °C, which is the initial temperature for the reaction reported in all studies analyzed. It was found that the specific reaction temperature may vary depending on the type of fat and the desired level of inhibition of trans fatty acid formation.

The analysis revealed that the most common definition of oil hydrogenation is the saturation of double bonds in unsaturated fats using nickel as a catalyst. This process involves a complex set of reactions in addition to the actual saturation. The equipment for stepwise hydrogenation has a relatively simple design. The main design features identified in all the studies analyzed include a vessel capable of withstanding a gauge pressure of 35–40 kPa, a stirrer, a heating and cooling mechanism, a hydrogen inlet, a pipeline, a pump for feeding the feedstock, and a sampling pipe for monitoring the reaction. This equipment allows for the control of three main parameters: pressure, temperature, and stirring speed.

The hydrogen pressure in the reaction, according to the analyzed data, is measured in the main reactor space and is controlled by an inlet valve. The headspace can also be vented to remove gaseous impurities such as methane, nitrogen, carbon dioxide, and carbon monoxide. However, this venting process results in some loss of hydrogen gas. Sánchez et al. reported that venting increases the flow of hydrogen through the reaction mass, resulting in increased mixing (Sánchez, M. A., Torres, G. C., Mazzieri, V. A. and Pieck, C. L., 2017). Several factors influence the mixing in the reactor. The main ones are the type and speed of the stirrer blades. In addition, the overall mixing effect is influenced by the design and number of heating and cooling coils, the presence of baffles, and the rate at which hydrogen enters through the perforated distribution ring at the bottom of the reactor. Heating of the oil in batch hydrogenation is typically achieved using high-pressure steam coils. The analyzed data showed that temperatures in the range of 140 to 225 degrees Celsius have been used for nickel-catalyzed hydrogenation. Jang et al. reported that higher temperatures could be achieved by initiating the reaction at a standard starting temperature and providing exothermic heat of reaction to raise it to the desired level (Jang, E. S., Jung, M. Y. and Min, D. B., 2005).

To initiate the hydrogenation process, the oil is pumped into the converter while a vacuum is created in the headspace, after which it is heated. At the same time, the catalyst is weighed and mixed in a catalyst mixture tank to form a slurry with a small amount of oil. Once the desired gassing temperature is reached, the catalyst is pumped into the reactor and thoroughly mixed with the oil. Hydrogen is then added to achieve the desired pressure. The reaction is initiated and the temperature is gradually increased to the operating temperature. To maintain the desired temperature, the reaction mass is cooled if necessary. The progress of the

reaction is monitored by observing changes in the refractive index. It has been found that most researchers point to the need for preliminary staged treatment of the oil before the hydrogenation process. The raw material should be cleaned, bleached and have a low soap content. According to Allen, the amount of soap substances in the fat should be less than 25 mg / kg. In addition, the oil must be dry to ensure optimal hydrogenation results. As for the hydrogen used in the process, the gas must also be dry and have a low amount of impurities. Modern hydrogen production plants using hydrocarbons can produce extremely pure hydrogen. On the other hand, older plants may produce hydrogen that contains some methane, carbon dioxide, and potentially significant amounts of nitrogen if the feed gas contained a high content of these gases. Some hydrogenation plants have been designed to extract hydrogen from stored liquid hydrogen, which serves as a reliable source of backup gas in case of a gas plant shutdown. According to Žula et al., liquid hydrogen has a high purity (Žula, M., Grilc, M. and Likozar, B. Hydrocracking). In general, both the oil and the hydrogen used in the hydrogenation process must meet certain criteria for purity and dryness to ensure the efficiency of the process.

It is worth noting that in the process of partial hydrogenation, a significant amount of trans-fatty acid isomers (TJK) is formed.

It has been found that the degree of unsaturation of the oil and various process conditions influence the formation of trans fatty acid isomers during hydrogenation. Table 1 provides an overview of how these factors affect TFA production. Since hydrogen plays a critical role in the trans isomerization process, it is important to supply sufficient hydrogen to the catalyst. This can be achieved by increasing the pressure or improving the mixing conditions. In addition, oils rich in unsaturated fatty acids require more hydrogen compared to highly saturated fats.

Table 1. The influence of process conditions and fat saturation on the hydrogenation process

Change parameter	Positive influence	
	Hydrogen concentration on nickel catalyst	Education of TJK
Temperature increase	–	+
Intensification of mixing	+	–
Increasing the catalyst content	–	+
Increased catalyst activity	–	+
Increased pressure	+	–
Increased content of unsaturated fatty acids	–	+

Conclusions

The study found that the most important characteristics of a catalyst for fat hydrogenation are its activity, durability, selectivity, and stability of isomer formation. It was found that catalyst selectivity is a key factor in obtaining target edible fats by stepwise hydrogenation. It was found that different researchers use different definitions of this term. The most successful definition of selectivity is the rate of various reactions during hydrogenation. The work demonstrated that reuse of the catalyst can lead to a decrease in selectivity. Thus, to obtain the most important components, its reuse should be avoided. The problem of forming trans-isomers of fatty acids, which reduce the food quality of fats, was identified as one of the main disadvantages of the stepwise hydrogenation technology. The main factors that contribute to the formation of trans-isomers of fatty acids were high temperature, catalyst specificity, and the use of raw materials with a high amount of unsaturated fatty acids.

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Section 4. Technical scieces in general

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OPERATING CONDITIONS OF ROLLING BEARINGS IN AGRICULTURAL MACHINERY, THEIR CAUSES OF FAILURE AND CONSEQUENCES

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Abstract

This article presents an analytical overview of the operating conditions of rolling bearings used in agricultural machinery, along with the causes and consequences of their failure. One of the main reasons for the failure of rolling bearings is fatigue-induced flaking and wear of the friction surfaces. Key contributing factors include external load effects on rolling surfaces; deformation of the rolling surface that increases localized contact stresses; internal defects of bearing components; reduction in surface hardness due to elevated temperatures from external heat sources; and corrosion of the rolling surfaces.

Keywords: *Rolling bearing, wear resistance, strength, hardness, lubricability, heat resistance, vibration resistance, corrosion resistance, friction unit*

In the design of modern machinery and agricultural equipment, between 150 to 350 types and sizes of bearings are used for various purposes. In this regard, the development of modern mechanical engineering has imposed high demands on friction units, particularly on bearing assemblies. One of the key measures to ensure these requirements are met is to enhance the wear resistance of bearing units.

For many types of bearing assemblies, the main criteria for improving wear resistance include strength, hardness, lubricability, heat resistance, vibration resistance, corrosion resistance, precision, and others (Ivanov M. N., 2008; Timofeev S. I., 2007; Lelikov O. P., 2006; Reshetov D. N., 1989; Shoobidov Sh. A., 2020; Mirzaev K. K., Shoobidov S. A., 2022).

In modern machine designs, various types and sizes of bearings are used depending on their type and installation location. These bearings must not only ensure wear resistance but also meet a range of other re-

quirements such as low noise operation, reduced metal consumption, and a high degree of standardization, among others.

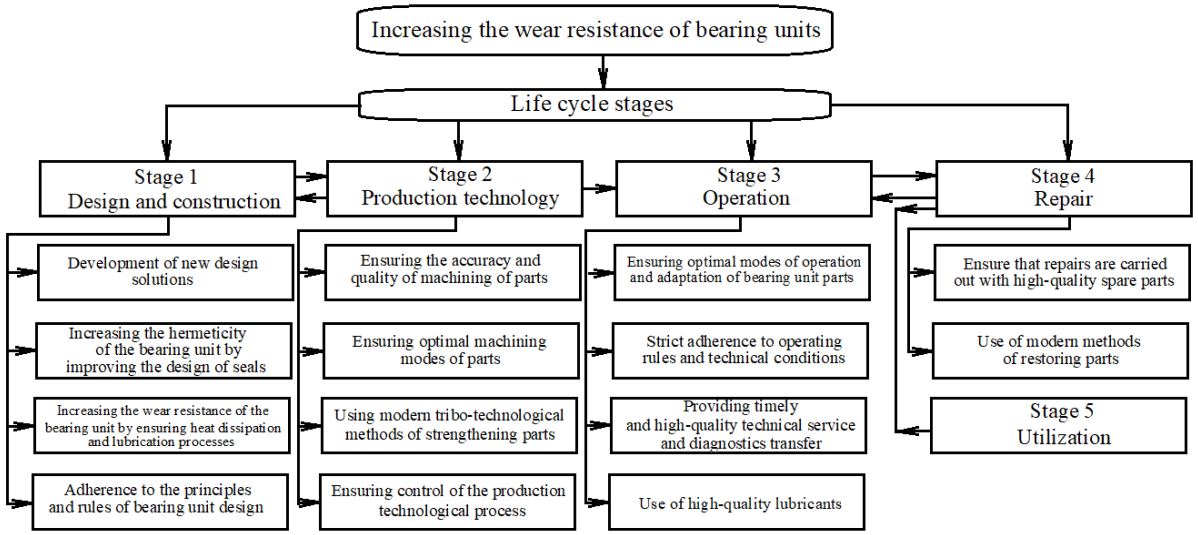
Despite continuous improvements in the design and operating conditions of bearing friction units, the issue of wear resistance in their components remains largely unresolved and continues to attract serious attention from designers, technologists, and users.

Analytical studies on failures due to insufficient wear resistance show that the service life of bearing components is significantly lower than the total service life of the machine – ranging between 30% to 60%. This results in increased labor and material costs for maintenance and repair during operation.

Therefore, enhancing the wear resistance of bearing friction units is a key engineering challenge that retains its relevance over time and requires various scientific approaches and directions.

To develop a scientific basis for a systematic approach to improving wear resistance throughout the entire lifecycle of mechanical products, future stages of mechanical engineering development should consider the integration of machine design, manufacturing, operation, and maintenance technologies (Suslov A. G. 2007; Fedonin O. N., 2001; Mirzaev K. K., Shoobidov S. A., 2022; Shaabidov Sh.A., Irgashev A., Mirzaev K. K. 2012). For instance, the operational cycle stages of bearing units are illustrated in the following diagram (fig. 1).

Figure 1. *Life cycle stages of bearing assemblies*



The issue of improving the wear resistance of bearing friction units remains consistently relevant, as trends in the development of science, technology, and engineering lead to increasing complexity in the design of friction units and their components. Additionally, operating conditions have become more demanding in terms of load, speed, temperature, vibration, and other parameters. Simultaneously, there is a trend toward reducing the external dimensions and specific mass of friction units, decreasing material and energy consumption, and increasing the degree of standardization (Chichinadze A. V., Brown E. D., Boucher N. A. and others. 2001; Shets S. P., 2011; Mirzaev K. K., Shoobidov S. A., 2022; Shaabidov Sh.A., Irgashev A., Mirzaev K. K., 2012).

Currently, in the construction of many machines and agricultural equipment, bearing assemblies are used that involve not only rolling but also relative sliding motions (rotational, reciprocating, or combined). The wide variety of bearing types, both individually and in combination with other structural elements, form bearing friction units with specific service life characteristics.

According to some sources, if new bearings are assembled correctly and operated according to standard parameters (lubrication, alignment, etc.), they can perform reliably and demonstrate high wear resistance throughout their calculated service life (Kogaev V. P., Drozdov Yu.N., 1991; Kuzmin V. A., 1990; Fadin Yu.A. 2004;

Mirzaev K. K., Shoobidov S. A., 2022). However, as bearings reach the limits of their operational lifespan, they tend to fail due to surface wear and fatigue-induced spalling.

Throughout the entire operational lifespan, bearing assemblies are subject to failures of varying intensity, necessitating additional costs for their elimination.

Analytical data shows that under real operating conditions, before a machine reaches its end-of-life stage, approximately 30% to 50% of its bearings are typically replaced.

Moreover, 40% to 70% of the downtime during maintenance of machinery is spent addressing bearing unit failures. More than 60% of bearing failures in agricultural machinery occur during actual usage.

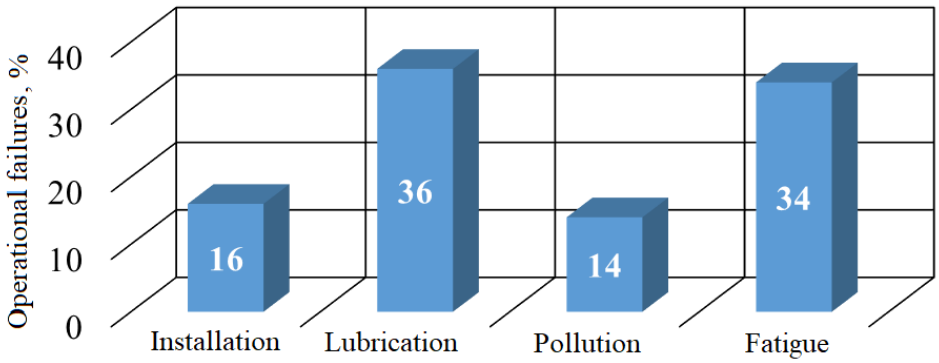
The percentage distribution of operational failures in machine and mechanism bearings is illustrated in figure 2.

The loss of wear resistance in bearings leads to operational failures that directly affect both operational safety and environmental conditions. During operation, the sudden failure of a machine or its components is diagnosed through technical condition monitoring, indicating whether a bearing needs to be replaced or not.

Operational costs related to the repair and maintenance of bearing assemblies can be 2 to 3 times higher than the cost of manufacturing them.

In practice, bearing assemblies are subject to gradual, sudden, and emergency failures during the use of machines. In such cases, the bearing may partially or completely lose its performance, failing to meet one or more of the functional requirements it was designed for. Therefore, timely identification of defects in rolling bearings is essential. Continued use of defective bearings can lead to the failure of not only other components of the unit but also the housing of the assembly itself. For this reason, it is important to develop methods to determine the type of downtime, identify the causes, and diagnose such conditions (Shets S. P. 2011; Shoobidov S. A., Mirzaev K. K., 2018; Shaabidov Sh.A., Nigmatullaev S. I., 2006; Zangiev A. A., Skorokhodov A. N., 2006; Mirzaev K. K., Shoobidov S. A. 2022; Shaabidov Sh.A., Irgashev A., Mirzaev K. K., 2012).

Figure 2. *Histogram showing the percentage ratio of bearing failures during machine and mechanism operation*



The defects of rolling bearings include the following: fatigue wear of friction surfaces; spalling of friction surfaces; abrasive wear; atmospheric corrosion; fretting corrosion; brinelling; false brinelling; surface scratches; assembly-related damage; overheating damage; load-induced damage; fracture and fragmentation of bearing elements; misalignment of bearing rings; damage to the separator; damage caused by improper lubrication; and thermal cracks on the outer surface of the outer race (Reshetov D. N., 1989; Shets S. P., 2011; Kuzmin V. A., 1990; Chermenskiy O. N., Fedotov N. N., 2003; Gorokhovsky G. A., 1999; Seregin A. A., 2010; Mirzaev K. K., Shoobidov S. A., 2022; Shaabidov Sh.A., Irgashev A., Mirzaev K. K., 2012).

One of the main reasons for the failure of rolling bearings is the spalling caused by fatigue wear on friction surfaces. The contributing factors to such wear include: the impact of external loads on the rolling surfaces; deformation of the rolling surfaces that increases localized contact stress; internal defects of bearing

elements; reduced hardness of friction surfaces due to increased temperature from external heat sources; corrosion of the rolling surfaces.

The fatigue-induced spalling of rolling bearings can be reduced, and their wear resistance can be improved by enhancing the tribotechnical properties of lubricants. In particular, the addition of anti-wear additives to the lubricant composition yields positive results.

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RESULTS OF RESEARCH OF THE MAIN PROPERTIES OF MULTI-FUNCTIONAL LUBRICANTS

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Abstract

The article is devoted to the study of the main properties of polymer-containing multifunctional lubricants based on tars of vegetable oils and technical animal fats. The compositions and results of studies on the determination of adhesion, lubricating, anti-friction and anti-wear properties, as well as the degree of washability from metal surfaces, are presented. The mechanism of lubricating action is revealed, and the process of applying these lubricants is modeled. The wear of spur gears of bevel gear reducers was studied when using lubricants based on tars of vegetable oils and technical animal fats. It was found that they increase the service life of reducers. The multifunctionality of the developed lubricants is expressed in the possibility of their use in the manufacture of agricultural machinery parts and their assemblies, in machining processes with increased pressure, in corrosion protection of parts, in inter-operational storage, and in friction units of machines.

Keywords: *multifunctional lubricant, properties, tar, polymer filler, adhesion, lubrication, wear resistance, friction coefficient, washability, service life*

Introduction

Various lubricants are used in friction units of technological machines. Therefore, much attention is paid to the creation of new lubricants with improved lubricating properties that reduce wear of friction surfaces.

Research and development work is being carried out to increase the wear resistance of friction units using multifunctional lubricants based on vegetable oil tars and industrial animal fats. The introduction of polymer additives into the composition of these multifunctional lubricants allows for an increase in the wear resistance of friction units due to the formation of a polymer film on the friction surface and, to some extent, makes it possible to regulate the tribotechnical properties of friction pairs (Shaabidov, Sh. A., Irgashev, A., & Mirzaev, K. K., 2012; Huang, Y., Chen, Q., Yang, J., Guo, P., Liu, X., Feng, K., ... & Zhou, F., 2025; Mikhnevich, N. N., & Smurugov, V. A., 1985; Chichinadze, A. V., Braun, E. D., Bushe, N. A., et al., 2001).

This article presents the results of studies of the main properties of multifunctional

lubricants based on vegetable oil tars and industrial animal fats.

Method

Table 1 presents the physicochemical parameters of technological lubricants based on vegetable oil tars and industrial animal fats, and table 2 presents the formulations of these lubricants, protected by copyright certificates (Garkunov, D. N., 2001; Mirzaev, K. K., & Shoobidov, Sh. A., 2022; Liang, B., Zhao, J., Li, G., Huang, Y., Yang, Z., & Yuan, T., 2019; Shaabidov, Sh. A., 1998).

Table 1. *Physicochemical properties of technological lubricants*

№	Indicator name	Standard	Test method
1.	Appearance	Homogeneous pasty mass from light brown to black	According to GOST 6243–75 Section I
2.	Smell	Specific, non-irritating	Organoleptic
3.	Viscosity, kinematic, at +50 °C, mm^2/s	45–150	According to GOST 33–82
4.	Density at 20 °C, g/sm^3	0,92–1,3	According to GOST 3900–85
5.	Acid number, mgKOH/g of lubricant	60–120	According to GOST 6243–75 Section 7
6.	Flash point in an open crucible, °C	not lower than 250	According to GOST 4333–87
7.	Corrosion tests on steel plates according to GOST 9045–80	Passes	According to GOST 9.080–77
8.	Removability with aqueous solutions of detergents, s	15–30	According to TU 37.066.211–89
9.	Water content, % no more than	5	According to GOST 11812–66

Table 2. *Lubricant recipe*

Components	Mass fraction of components, mass.%									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Recipe for TE based on tars according to A.s. No. 1570285										
1. LMWPE	10	–	–	–	–	–	–	–	–	–
2. MEA	–	–	3	0,5	0,5	3	3	3	0,5	0,5
3. Oxyphos B-1	–	–	0,3	0,3	5	0,3	5	5	5	0,3
4. LMWPE production waste	–	10	15	3	15	3	3	15	3	15
Recipe for TE lubricant according to A.s. № 1626676										
1. Copper oxide	3	5	10	12,5	5	20	–	–	–	–
2. Aerosil	5	10	10	7,5	10	10	–	–	–	–

Compo-nents	Mass fraction of components, mass.%									
	1	2	3	4	5	6	7	8	9	10
3. Sunflower oil	5	15	15	10	5	15	–	–	–	–
4. Liquid soap	8	8	10	9	8	10	–	–	–	–
5. Mixture of vegetable oil tars and technical fats in a mass ratio of 1:1, the rest up to 100%.										

When manufacturing parts using the drawing method without lubrication, the bottom of the workpiece broke off, and the drawing force was 1.3...1.4 times higher than when drawing with TE (fig. 1). Thus, when drawing 12X18H10T steel with a drawing degree of 2.0, TE ensures the production of high-quality parts, and Ukrinol 16u, machine oil + MoS_2 lead to the bottom breaking off and metal sticking to the matrix (Shaabidov, Sh. A., 1996; Shabidov, Sh. A., 1996; Reeves, C. J., Menezes, P. L., Lovell, M. R., & Jen, T. C., 2015; Mirzaev, K. K., & Mustaeva, B. U., 2019).

Figure 1. *Dependence of the drawing force on the punch stroke: 1-Ukrinool 16u; 2-machine oil + MoS_2; 3-chalk; 4-graphite; 5-TE*

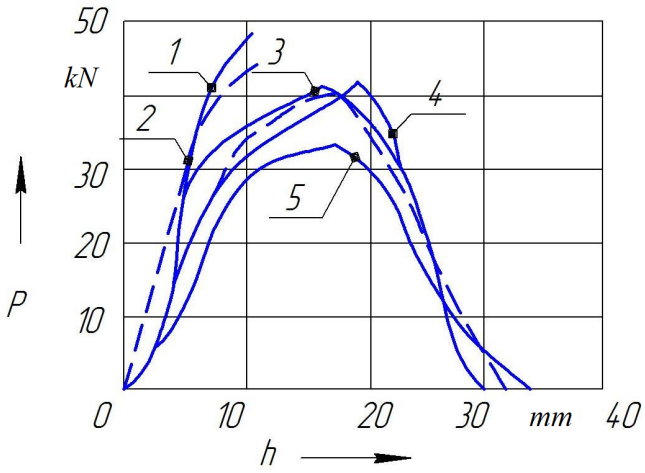
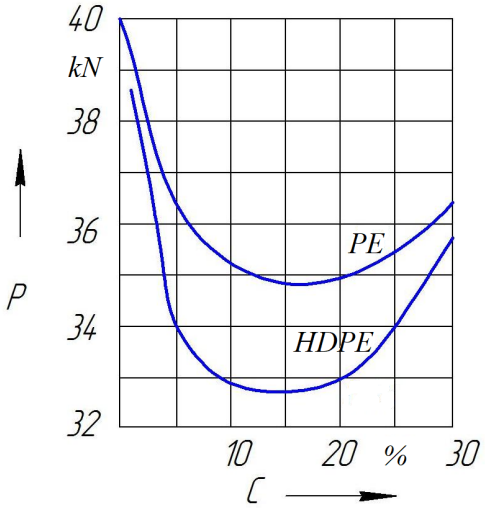


Figure 2. *Dependence of the change in the drawing force on the concentration of the filler in the tar*



A mandatory requirement for the polymer filler TE for stamping-drawing are high friction and film-forming properties. Polymers with a glass transition temperature and flow rate below 250...300 °C, i.e. the stamping temperature, are capable of forming adsorption-plasticized layers on friction surfaces. This ensures a reduction in the drawing force to a filler concentration of 15% (fig. 2). With an increase in the concentration of the polymer filler above 15%, the viscosity of the TE increases, the shear resistance between the monolayers of the lubricant and its components adsorbed on the metal surface increases. Measurement of wear of parts made of 5XHM steel showed that its value when using the developed TE was 0,4...0,6% and was at the level of oil lubricants and is explained by the possibility of hydrogenation of the surface layers of the metal due to mechanochemical reactions in the contact zone.

As the research results have shown, the developed TE based on tars have lower friction coefficients than traditional compositions, but their penetrating ability, which is of particular importance under the conditions implemented during mechanical processing, in friction units, during conservation of ACM, where the adhesion of the TE to the working surfaces is important, has practically not been studied. Fig. 3 shows the dependencies reflecting the influence of the concentration of monoethanolamine (MEA or triethanolamine TEA) on the adhesive properties, and fig. 4 shows the friction force from the load for tars containing PE (polyethylene) as a filler.

The increase in the force and coefficient of friction with increasing polymer concentration is explained by the following mechanism. The surface-active TE, adsorbed on the surfaces of the metal being processed, plasticizes its surface layer, reduces its yield point and facilitates shear formation. The formation of the thinnest, easily deformable layer occurs during the chemical interaction of metal atoms with the polar groups of molecules of the active components of the TE, and this leads to the formation of layers of chemoadsorption metal soaps, sulfur- and phosphorus-containing compounds on the metal surface, firmly bound to the metal surface and reducing the force and coefficient of friction. Adhesive properties and the coefficient of friction are described by the equations:

$$A = 0{,}5 + 0{,}3563\ C - 0{,}0007776\ C^4 \quad (1)$$

$$f = 0{,}0429 - 0{,}00628\ C + 0{,}00139\ C^2 \quad (2)$$

Figure 3. *Effect of filler concentration in tar on adhesion: 1-PE; 2-HDPE; 3- LMWPE*

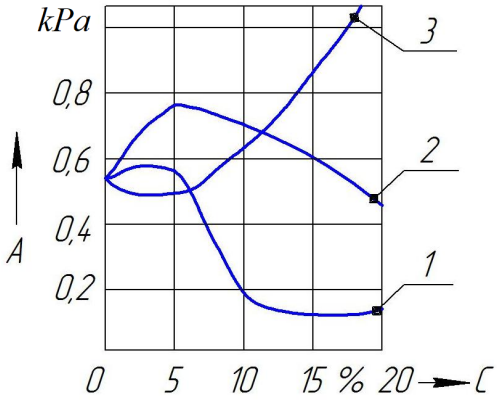


Figure 4. *Dependence of friction force on load for tars: 1–5%; 2–10%; 3–15%; 4–20%*

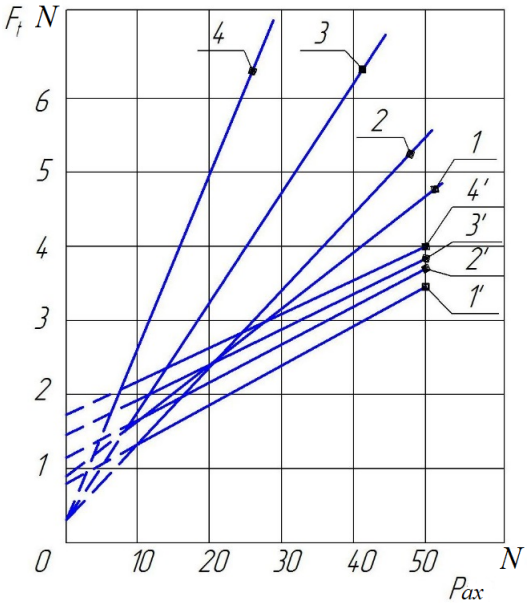


Table 3 shows the results of determining the adhesive properties of tar-based lubricants. Table 3 shows that lubricant compositions according to A.s.1570285 No. 3, No. 5, No. 8 and No. 10 have higher adhesive properties than the other compositions. In these compositions, the concentration of PE waste was 15%.

Table 3. *Adhesive properties of tar-based lubricants*

Composition of TE A.s. No. 1570285	Adhesion, kPa	Composition of TE A.s. No. 1626676	Adhesion, kPa
1	0,58	1	2,36
2	0,15	2	2,53
3	2,41	3	2,71
4	1,54	4	2,87
5	1,98	5	2,49
6	1,44	6	2,41
7	1,73	–	–
8	2,26	–	–

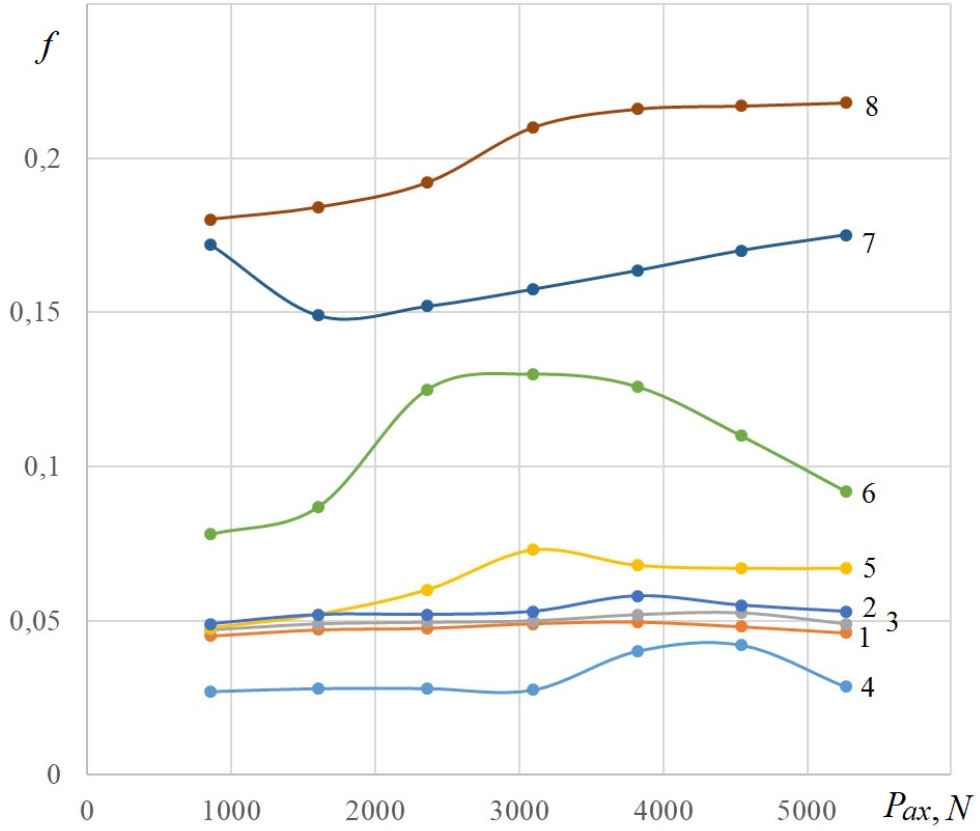
Composition of TE A.s. No. 1570285	Adhesion, kPa	Composition of TE A.s. No. 1626676	Adhesion, kPa
9	1,68	–	–
10	2,56	–	–

Compositions according to A.s.1626676 had adhesion within 2.34...2.87 kPa, which shows more stable adhesive properties of these lubricants.

Fig. 5 shows the change in the friction coefficient from the axial load at the concentration of PE and LMWPE. As can be seen from the graphs, the use of high-pressure PE production waste – liquid LMWPE in all concentrations has a low friction coefficient within 0,027...0,054 in comparison with powdered PE – 0,051...0,175. Based on the research results, it can be stated that TE lubricants are characterized by a low friction coefficient and high adhesive properties.

When studying the influence of polymer fillers on the lubricating properties of tar-based lubricants, polymeric materials with different molecular weight and dispersion were used: finely dispersed PE with a particle diameter of 0,2 ... 0,3 mm and its production waste LMWPE with a molecular weight of 800 ... 2000 conventional units. Fig. 6 and fig. 7 illustrate the influence of the concentration of polymer fillers on the extreme pressure and antiwear properties of tars. The introduction of PE into tar up to 10% leads to some improvement in the lubricating properties, an increase in the critical load from 800 ... 850 N to 900 ... 960 N (fig. 6).

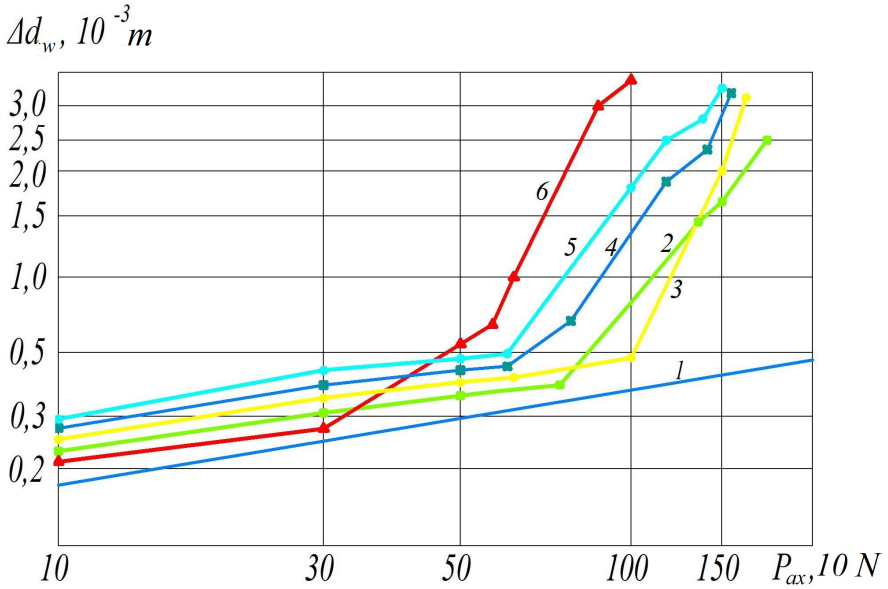
Figure 5. *Change in the friction coefficient from the axial load for tars with polymer fillers: 1...4 – LMWPE; 5...8 – PE (respectively 5; 10; 15 and 20%)*



A further increase in the PE concentration leads to an increase in the diameter of the ball wear spot, the force and coefficient of friction, and a decrease in the loads P_k and P_s (respectively, the critical load and the welding load of the balls). The use of LMWPE as

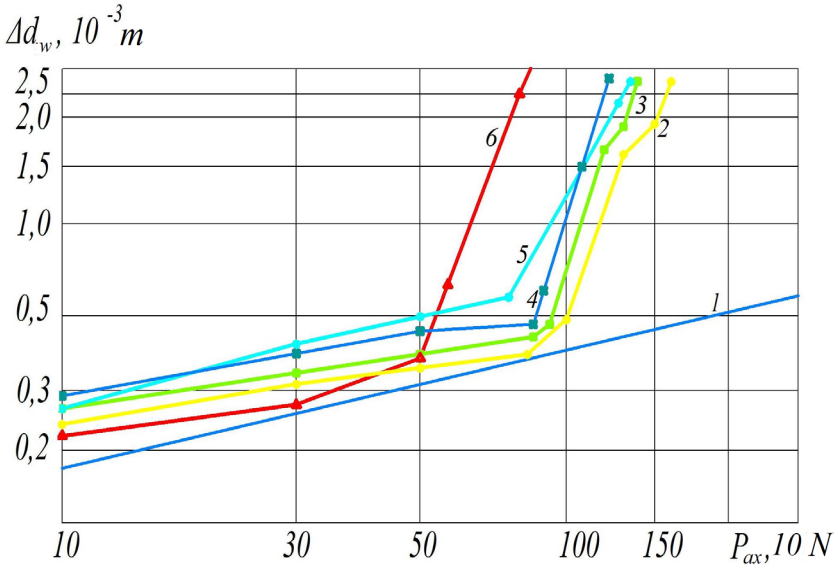
a filler (fig. 7) up to 5% leads to an improvement in the lubricating properties of tar, an increase in the critical load to 950...1000 N, i.e. by 11,1...11,76%. A further increase in its content reduces P_k and P_s, and the diameter of the ball wear spot increases. The results of our studies are presented in detail in (Shaabidov, Sh. A., 1998). Machine oil has good lubricating ability only at low loads not exceeding P_{ax} = 300 N. Increasing the axial load leads to a sharp increase in the wear spot of the balls and their welding at a load of 800 ... 900 N. Tar with LMWPE has a higher lubricating property than industrial oil and graphite lubricants at low and medium loads, despite the fact that the welding load does not exceed 1700 N. In addition, the developed TS lubricant has better performance properties, does not contaminate the surface of parts, and is biodegradable. Thus, the results of the studies made it possible to substantiate and establish that the use of liquid low-molecular PE in tars of vegetable oils and technical animal fats as a filler allows replacing scarce powdered polymeric materials without deteriorating the lubricating properties of TE.

Figure 6. *Dependence of wear scar diameter on axial load: 1 – line of elastic deformation of balls according to Hertz; 2 – tar+5% LMWPE; 3 – tar +10% LMWPE; 4 – tar +15% LMWPE; 5 – tar +20% LMWPE; I–L-A-22 oil*



The method of mathematical planning of the experiment was used to optimize the TS compositions based on tars, which have the best lubricating and technological properties (Shaabidov, Sh. A., 1996; Shabidov, Sh. A., 1996). The developed lubricants underwent extensive production tests in production conditions at the Kalmakir Mining Administration of the Almalyk Mining and Metallurgical Plant. The tests were conducted on heavily loaded open friction units of the EKG-10 excavator with a bucket volume of 10 m^3. The efficiency of the lubricants was determined relative to the SS lubricant – synthetic solid oil GOST 4366–76, used by the plant. The conditions for conducting production tests: air dustiness of 3...8 g/m^3, heating temperature of the tested friction units under direct sunlight 80...92 °C. Comparative tests have shown the following: TE lubricants reduce wear intensity by 20...26%; friction coefficient by 15...20%; increase the operating temperature of the lubricant by 34...41 °C and the seizing onset load by 18...25%. The developed lubricants based on tars with polymer fillers are recommended for heavily loaded open gears, for lubricating rolling and sliding bearings of industrial equipment, friction units of the ACM and mobile machines in order to reduce wear intensity, friction coefficient, increase the operating temperature of the lubricant and the seizing onset load.

Figure 7. *Dependence of wear scar diameter on axial load: 1 – line of elastic deformation of balls according to Hertz; 2 – Gomel MZhK tar; 3 – tar+5% PE; 4 – tar +10% PE; 5 – tar +15% PE; 6 – I–L-A-22 oil*



X-ray structural studies have shown that the use of TE has a positive effect on the technological heredity of parts, reducing their tendency to warping and corrosion during operation, due to a decrease in the level of internal stresses. Table 4 shows the results of determining the internal stresses of the I kind for samples made of 12X18H10T steel. It was not possible to determine the crystallite sizes and microstresses of the II kind, because the samples are two-phase as a result of stamping and the intensity peaks for the |111| (γ-Fe) and (α-Fe) reflections overlap due to the small difference in interplanar distances.

Table 4. *Internal stresses of the I kind for samples made of steel 12X18H10T*

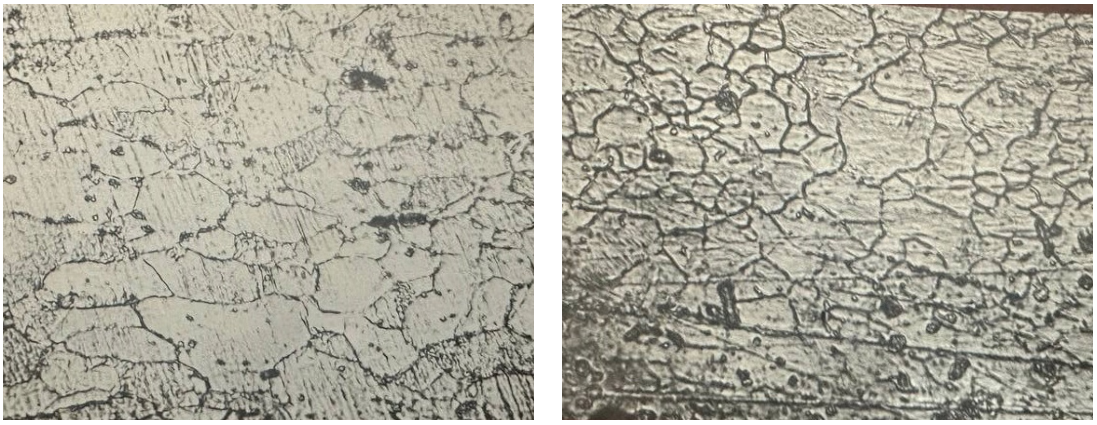
Samples	Change in interplanar distance along lines Δd, Nm				Sum of internal stresses along lines, MPa (σ1+σ2)			
	111	002	202	113	111	002	202	113
No.1 wall	0,00151	–0,0007	–0,00024	–0,0001	6500,1	4041	1839	1001
No.1 coal and wall No.10	–0,0008	–0,0003	–0,0002	–0,00003	3370	1360	1346	250
wall	–0,0011	–0,0006	–0,0004	–0,0002	4760	3227	3067	148

The parts manufactured by stamping are in a two-phase state on the surface. The texture is weakly manifested, since the corresponding intensities in the diffraction patterns are suitable for austenite (γ-Fe) and pearlite (α-Fe). Internal stresses appear due to the difference in the physical and mechanical properties of these phases.

The results of metallographic and X-ray structural analysis on samples made of 12X18H10T and 08 Yu steel showed (Shaabidov, Sh. A., 1998) that the composition and type of TE significantly affect the nature of the distribution and change in microhardness, grain texture, and the magnitude, direction, and distribution of residual internal stresses of the first kind during the manufacture of parts. Fig. 9 shows the microstructure of 12X18H10T steel samples after stamping using factory (a) and polyfunctional tar-based lubricant (b).

Figure 9. *Microstructures of samples made of 12X18H10T steel (400^x)*

a **b**



And this once again gives grounds to assert that, based on a rational choice of the composition and type of TE, it is possible to purposefully influence and, to a certain extent, control the processes of wear of friction units and corrosion during the operation of the ACM and metal structures.

Table 5. *For the gears in gearboxes, the average comparative wear along the length of the tooth, u_q (mm/(N/mm))*

Gearbox number	Section along the tooth length					
	I		II		III	
	H_1	H_2	H_1	H_2	H_1	H_2
Cantilever gear						
1	0,388 0,361	0,656 0,592	0,346 0,313	0,538 0,501	0,088 0,074	0,013 0,012
2	0,212 0,197	0,420 0,393	0,147 0,131	0,322 0,297	–	–
3	0,272 0,261	0,785 0,674	0,191 0,180	0,558 0,503	–	–
4	0,484 0,424	0,329 0,292	0,245 0,202	0,198 0,167	–	–
Intermediate gear						
1	0,345 0,309	0,331 0,295	0,304 0,281	0,304 0,264	0,025 0,021	0,025 0,020
2	0,314 0,279	0,275 0,255	0,177 0,149	0,321 0,286	0,307 0,270	0,297 0,219
3	0,213 0,178	0,300 0,283	0,222 0,199	0,444 0,402	0,260 0,202	0,540 0,495
4	0,430 0,393	0,353 0,309	0,376 0,312	0,340 0,294	0,305 0,268	0,301 0,264
Gear wheel						
1	0,681 0,505	0,476 0,421	0,598 0,532	0,376 0,311	0,292 0,224	0,670 0,516
2	0,632 0,581	0,528 0,469	0,418 0,394	0,484 0,410	0,229 0,201	0,132 0,110

Table 6. *Tooth wear rate, u mkm/hour*

Details	Grease	1	2	3	4
Console gear	Litol (grease)	3,280	1,921	1,721	1,061
Intermediate gear		1,725	1,203	1,184	0,942
Gear wheel		3,405	1,385	1,390	1,037
Console gear	TG based on bitumen	3,052	0,862	1,478	0,875
Intermediate gear		1,545	0,625	1,117	0,825
Gear wheel		3,012	1,230	1,269	0,931

Table 7. *Wear resource of gears for bevel gears [∑t], hours*

Details	Grease	1	2	3	4
Console gear	Litol (grease)	351	530	541	768
Intermediate gear		667	849	787	865
Gear wheel		338	735	670	786
Console gear	TG based on bitumen	377	1182	630	931
Intermediate gear		745	1630	834	988
Gear wheel		382	828	734	875

Conclusions

1. Based on the conducted research, multifunctional technological lubricants based on tars of plant origin have been developed and introduced into production, which in combination provide the required reliability and improve the operational characteristics of the parts and units of the ACM.

2. The mechanism of lubricating action has been established and the TE compositions with the best indicators have been optimized.

3. Based on the rational choice of the composition and type of TE, it is possible to a certain extent to purposefully influence and control the processes of wear of friction units and corrosion during manufacture, during operation of the ACM and metal structures.

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ANALYSIS OF AUTOMATION AND DIGITAL TECHNOLOGIES IN THE NAIL SERVICE

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Abstract

The article discusses the introduction of automation and digital technologies in nail services, with a focus on modern innovative solutions that aim to improve the efficiency of beauty salons. These solutions include online booking systems, automated inventory management, and customer database management, as well as the use of digital tools for nail art design. Notes the impact of these technologies on enhancing the quality of services, reducing waiting times, and increasing customer satisfaction. It also discusses challenges and opportunities for further digitalization in the nail industry, such as the integration of artificial intelligence and personalized services.

Keywords: *automation; digital technologies, nail service, customer base management, nail design, artificial intelligence, digital devices*

Automation and digital technologies are transforming the nail service industry. Traditionally, this industry has been based on manual labor and individual craftsmanship. However, with the development of digital tools, it is becoming more advanced and efficient. Today, beauty salons are implementing online systems for registration, sales, customer relationship management (CRM), and training. This allows for a more personalized approach to customer service, convenience in recording and payment, and reduction of human error in business management.

Automation makes it easier to plan work, manage inventory, and analyze activity effectiveness, leading to lower costs and higher profits. This is a positive trend for the industry, as it improves the overall experience for both customers and businesses.

Digital technologies are also opening up new opportunities for promotion through social media and mobile apps, creating unique communication channels with customers and expanding the reach of businesses. As a result, the integration of these innovations into the nail service industry is becoming a crucial factor in the success and sustainability of modern salons. This article will explore the main areas of automation and the technologies being used, as well as their impact on the industry.

The modern beauty industry is facing increasing competition and constantly evolving customer demands for quality and fast service. Digital technology is becoming a crucial

tool for enhancing the efficiency of nail salons. Automation enables salons to streamline client scheduling, manage craftsmen's schedules, track materials, and improve marketing strategies. During the COVID-19 pandemic, digital tools provide a secure and convenient experience, including online booking and contactless payments.

Additionally, implementing digital solutions reduces costs, improves business transparency, and increases profit margins. This is particularly beneficial for small and medium-sized enterprises seeking to adapt to changing market conditions.

The main goal is to identify and implement effective methods of using digital technologies to significantly improve the quality and speed of customer service, optimize salon management, and increase consumer loyalty and business competitiveness.

The study aims to:

– analyze modern digital tools and software for nail services;
– identify the advantages and potential challenges of automation;
– develop recommendations for successfully integrating technology into beauty salons' daily operations;
– assess the impact of digitalization on the economic and operational performance of the industry.

The research helps to understand how technology can transform the nail service industry, making it more modern, convenient, and profitable. Automation and digital technologies have been introduced in the field of nail services relatively recently, as part of the development of the IT industry and digitalization of businesses.

Previously, nail services were mostly a traditional industry with limited use of technology. Focus was on craftsmanship and manual processes, such as recording customers and accounting for materials and finances in salons.

However, with the growing popularity of computers and the internet, specialized programs for beauty salons started to emerge. These programs included CRM systems and tools for managing customer databases and scheduling appointments. These tools have made the process of managing a nail salon more efficient and streamlined.

The advent of cloud-based services, mobile apps, and online platforms has greatly transformed the way nail salons manage their businesses. Automation has impacted customer records, material accounting, marketing (e.g., mailing lists, promotions), and the analysis of salon performance. During this time, efforts to integrate digital technologies in order to enhance service quality and optimize business operations have begun.

The COVID-19 pandemic has significantly accelerated the digital transformation of the beauty industry. The use of online booking, contactless payments, virtual consultations, social media and automated customer service systems has become the norm. Research is ongoing into the implementation of AI, automated inventory management and personalization through digital technologies.

The history of nail service automation and digitalization is closely linked to the broader trend of business digital transformation and the proliferation of internet technologies. This has provided salons with new tools to improve efficiency, making this topic an important area for research and practical implementation.

Note that there are several ways to study automation and digital technologies in nail services.

1. *Analyzing literature and market research*. Reading scientific publications, industry articles, reports, and reviews on digital technology in the beauty industry can help you understand current trends and the direction of automation in nail services.
2. *Case studies*. Analyzing specific salons that have implemented digital tools like CRM systems, online booking, mobile apps, and inventory management can help identify the benefits and challenges of automation.
3. *Surveying and interviewing experts*. Gathering qualitative and quantitative data about the perception, adoption level, and expectations regarding automation can provide valuable insights.
4. *Experimentation*. Implementing and testing new digital solutions in real-world salons can help assess their effectiveness and impact on productivity and service quality.

5. *Analysis of User Data and Metrics*. Study of statistics on service times, customer records, turnover, and material consumption using digital systems to determine the results of automation.
6. *Comparative Analysis*. Comparison of traditional working methods with automated processes based on criteria such as efficiency, speed, customer comfort, and error reduction.
7. *Technological Monitoring*. Tracking of innovations in the IT field that could be adapted to nail services, such as artificial intelligence, machine learning, mobile applications, and cloud services.

These combined methods provide a unique opportunity to comprehensively study and evaluate the impact of digital technologies and automation on the development of the nail industry.

The modern practice of automation and the introduction of digital technologies in the nail industry is a complex process that significantly transforms the traditional way of doing business for nail technicians and the management of salons. One of the key aspects of this transformation is the use of specialized online platforms and customer relationship management (CRM) systems, such as Fresha, Booksy, and Schedulista. These platforms allow customers to easily book appointments through websites or mobile apps, and nail technicians to efficiently manage their schedules, customer databases, and service histories. This automation not only reduces the workload on receptionists but also minimizes mistakes associated with manual bookings. The digitalization of nail services is part of the broader trend towards digital transformation in the service industry (Martynova K. S., Ryndina S. V., 2022, p. 35).

In addition, modern salons are implementing systems for automated accounting and warehouse management. These systems allow for the timely control of material consumption and stock replenishment, avoiding both surpluses and shortages of professional cosmetics and tools. Digital solutions also help to optimize financial reporting and analysis by tracking the profitability of individual services and the performance of each technician.

Another important area of development is the use of digital marketing and communication tools. Automated email lists, review management, promotions, and loyalty programs through SMS, email, and social media allow salons to retain customers and attract new audiences. Many salons have created their own mobile apps or integrated with popular platforms, significantly improving the customer experience through convenient ordering, payment, and service status tracking (Table 1).

Table 1. *The impact of various social networks on the promotion of manicure services*

Platform	Advantages for manicure promotion	Disadvantages
Telegram	High visual appeal, opportunity to showcase works, storytelling, targeted advertising	High competition, the need for constant content updates
Classmates	A variety of content formats (photos, videos, text), opportunities for targeted advertising	Less interest among the younger audience, low engagement
Pinterest	A platform for visual search, high conversion through visual images and ideas	Fewer opportunities for real-time customer interaction
VK	Video content, the ability to create a viral effect, audience engagement through trends and challenges	Requirements for creative content, rapid trend changes

Online platforms for booking appointments are systems that allow customers to choose the date and time of their visit to a salon independently. Platforms like ZenBooker, Booksy, and Acuity Scheduling provide salon owners with the opportunity to automate the booking process, which greatly simplifies the scheduling process and eliminates the need for manual management. These solutions minimize the risk of errors, reduce time spent on organizing the schedule, and increase efficiency (Sumenkova A. N., 2021, p. 91).

New digital devices and equipment with built-in sensors and timers are being developed by craftsmen to improve the quality and safety of their procedures. For instance, gel polish drying lamps with automatic timing or hardware manicure machines that adjust settings based on skin type and nail plate condition (see Fig. 1). Additionally, QR codes are being actively implemented, allowing for the storage of data on performed procedures, recommendations, and material compositions. This helps to personalize service for each client.

Figure 1. *An example of 3D printing on nails (Zhusupova A. T., 2024)*

Online courses, webinars, and training platforms are becoming increasingly popular as a way to improve skills for professionals. This provides access to new techniques and innovations, without the need for time off from work or travel to seminars. These opportunities significantly expand one's professional horizons and help maintain a high level of competence.

Additionally, modern digital solutions allow owners and administrators to collect and analyze data on customer preferences, service popularity, and marketing effectiveness. This helps them make informed management decisions and optimize business processes, leading to improved quality of service. The digital transformation of nail services increases their competitiveness, enhances the customer experience, and promotes more efficient use of resources. This allows craftsmen and salons to better organize their work and provide high-quality, personalized services to their clients.

The challenges in the implementation of automation and digital technologies in the nail industry are associated with various technical, organizational, and human factors. Firstly, salons face high costs in implementing modern digital systems. This is particularly challenging for small businesses with limited budgets, as they require additional investments in training staff.

Secondly, a lack of digital literacy among nail technicians and administrative staff can hinder the effective use of new technologies. Difficulties in mastering software interfaces, fear of change, and low motivation can lead to partial or incorrect use of software solutions.

Thirdly, technical issues like platform failures, internet connectivity problems, hardware incompatibilities, and inadequate support from software providers can significantly reduce the efficiency of automation.

In addition, there is a risk of confidentiality of customer data when using online databases and applications. It is necessary to protect personal information from leaks and hacks. Not all salons pay enough attention to cybersecurity issues, which can lead to the loss of sensitive data.

The adaptation of business processes to a digital format is also an important issue. Many traditional working methods are not compatible with a digital environment, making it difficult to schedule appointments, record materials, and interact with customers.

Finally, the introduction of new technologies is not always followed by adequate analytics and adjustments to business strategies. This can lead to investments in automation not bringing the expected increase in efficiency or improvement in service quality.

Despite the obvious advantages, the process of automation in the nail industry faces serious challenges that require an integrated

approach and professional training. To successfully and fully utilize digital solutions, it is essential to provide system support and ensure the availability of technology for different business categories.

To address these challenges, we propose an integrated and step-by-step approach. Firstly, it is crucial to make technology accessible for various business categories by implementing flexible payment models, offering equipment rental, and utilizing cloud services. This will reduce initial costs and make automation more feasible for smaller salons.

Secondly, it is vital to enhance the digital skills of staff through regular training sessions, webinars, and workshops. Additionally, creating user-friendly software interfaces tailored to the specific needs of nail technicians is essential. These measures will ensure a smooth transition to automation and maximize the benefits of digital technology in the nail industry.

Technical support should be available promptly and easily accessible, including monitoring of systems and regular updates of software to prevent failures and ensure compatibility. To protect customer data, reliable cybersecurity systems must be implemented, encryption should be used, and strict compliance with legislation on personal data protection must be ensured.

It is essential for the organization to adapt business processes to a digital format through expert consultations and the use of analytical tools to optimize salon operations and evaluate the effectiveness of new technology implementation. Additionally, it is crucial to foster a strategic understanding of automation among owners and employees to increase motivation for change and facilitate the integration of digital solutions into daily operations, ultimately leading to improved service quality and customer satisfaction.

The practice of automation and introduction of digital technologies in nail services is an important step in the industry's development, aiming to improve salon efficiency, enhance customer experience, and optimize business processes. Using modern software solutions, such as online booking, digital accounting, and data analytics systems, reduces the human error factor, saves time on routine tasks, and increases profitability. However, successful implementation demands attention to staff training, adaptation of technology to specific services, and protection of customer data.

Digitalization of nail services not only enhances competitiveness but also creates a comfortable environment for both customers and employees. This process is an integral part of the modern beauty industry.

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Contents