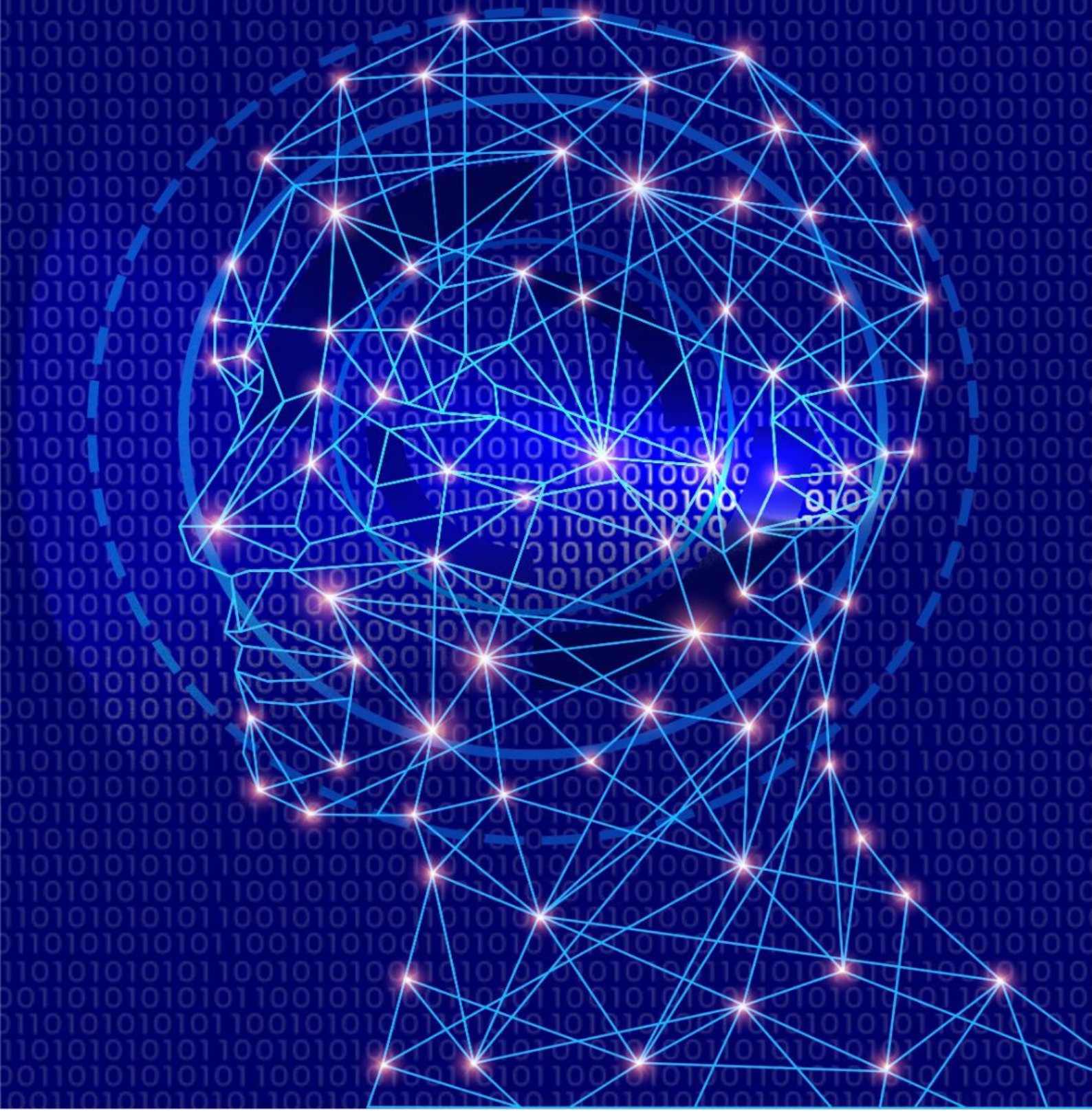
International Journal of

ADVANCES IN ARTIFICIAL INTELLIGENCE RESEARCH

AAIR

Volume 5, Issue 1, 2025

ISSN: 2757-7422



International Journal of ADVANCES IN ARTIFICIAL INTELLIGENCE RESEARCH

Advances in Artificial Intelligence Research

https://dergipark.org.tr/aair

Date of Publication	February 2025
Language	English
Frequency	Published twice in a year
Graphic designer	Özden Işıktaş

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International Journal of ADVANCES IN ARTIFICIAL INTELLIGENCE RESEARCH

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Advances in Artificial Intelligence Research (AAIR)
ISSN 2757-7422
www.dergipark.com/aair/

Vol. 5 (No. 1), pp. 1-6, 2025
doi: 10.54569/aair.1700682
Published online: June 16, 2025

Hybrid Visual-Textual Product Recommendation System for E-Commerce Platforms

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Abstract

Today, e-commerce sites provide a large number of products to users. However, presenting the right products to users is important for both customer satisfaction and increasing company revenues. Recommendation systems are systems that offer personalized product suggestions by analyzing user preferences and behaviors. This study presents a novel hybrid product recommendation system that integrates collaborative filtering and content-based filtering methods, enhanced by deep learning techniques. By using both visual and textual product features through BERT and CLIP models, our system addresses cold-start problem and real-time performance constraints. The system has been successfully deployed on the Cimri e-commerce platform, providing personalized recommendations that adapt to evolving user preferences while maintaining computational efficiency.

Keywords: *Product Recommendation System, E-Commerce, Collaborative Filtering, Content-Based Filtering, Hybrid Method*

1. Aims and Scope

With the rapid advancement of the internet and digital technologies, e-commerce has become a cornerstone of modern consumer behavior. Millions of users engage with online shopping platforms daily, navigating through an overwhelming number of products and services. This digital abundance, while offering variety, creates a significant challenge: enabling users to find the most relevant items efficiently and accurately [1]. To address this issue, recommendation systems have emerged as critical components in digital commerce infrastructure. Recommendation systems are intelligent software tools that aim to personalize the user experience by analyzing large datasets related to user behavior, preferences, and item attributes. Their main objective is to predict user interest in items and provide tailored suggestions, thereby enhancing both user satisfaction and commercial success [2]. These systems are now ubiquitous across platforms such as Amazon, Netflix, and Spotify, where personalization directly influences user engagement and retention [3]. There are three main types of recommendation techniques: collaborative filtering, which bases suggestions on the preferences of similar users; content-based filtering, which relies on item features and user profiles; and hybrid methods, which combine both approaches to overcome individual limitations [1]. Collaborative filtering can suffer from cold-start problems and data sparsity, while content-based filtering may struggle with limited feature diversity. Hybrid models attempt to leverage the strengths of each to improve recommendation quality.

In this study, we propose a hybrid recommendation system for the Cimri e-commerce platform that combines collaborative and content-based filtering with deep learning. We utilize pre-trained Turkish BERT and RoBERTa models for textual analysis and the CLIP model for visual understanding, creating a multimodal approach that comprehends products through both dimensions. We implement a dynamic personalized similarity metric that adapts to individual preferences over time. Using real-world data from Cimri, we evaluate this system across multiple metrics including precision, recall, F1-score, novelty, and serendipity. Our approach effectively addresses common challenges like the cold-start problem while maintaining real-time performance in a production environment.

2. Materials and Methods

In this study, a hybrid product recommendation system was developed by integrating two widely used techniques: collaborative filtering and content-based filtering. The dataset used consisted of real-world e-commerce records, including user purchase history and product features.

2.1. Dataset and Preprocessing

The first step involved creating a user-item interaction matrix. This dataset contained user behavior data (clicks, views, purchases), product metadata (categories, brands, specifications), and product images and textual descriptions. All data processing was conducted in compliance with personal data protection regulations

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Received: 25/April/2025; Accepted: 29/May/2025.

(KVKK), with sensitive categories excluded from recommendations.

For collaborative filtering, both user-based and item-based approaches were applied. User-based filtering identifies similarities between users based on their ratings or purchase behaviors, while item-based filtering focuses on the relationship between items based on user interactions. For content-based filtering, item attributes such as category, brand, and description were utilized.

2.2. Feature Extraction

For textual feature extraction, we employed a pre-trained Turkish BERT model fine-tuned on our product corpus. The model architecture consists of 12 transformer layers with 768-dimensional embeddings, producing a dense vector representation for each product based on its title and description. The fine-tuning process involved: Pre-processing product titles and descriptions (tokenization, stop-word removal), Training on a corpus of 2.5 million product descriptions and Optimizing with a contrastive learning objective to ensure similar products are positioned closely in the embedding space. The resulting embeddings capture semantic relationships between products, enabling the system to understand conceptual similarities beyond simple keyword matching.

Visual features were extracted using the CLIP (Contrastive Language-Image Pre-training) model [7], which provides a unified embedding space for both images and text. We utilized the ViT-B/32 variant, which processes images through a Vision Transformer architecture. The visual embedding pipeline included: Image preprocessing (resizing, normalization), Feature extraction through the CLIP vision encoder and Projection into a 512-dimensional embedding space. This approach enables the system to capture visual similarities between products that may not be evident from textual descriptions alone.

2.3. Collaborative Filtering

Collaborative filtering makes recommendations by taking into account user similarity and product similarity. By using users' data, users' site usage, lifestyle, shopping habits, etc., were used to fill in the 'Miser's Choice' tool on the detail page of the product they were interested in.

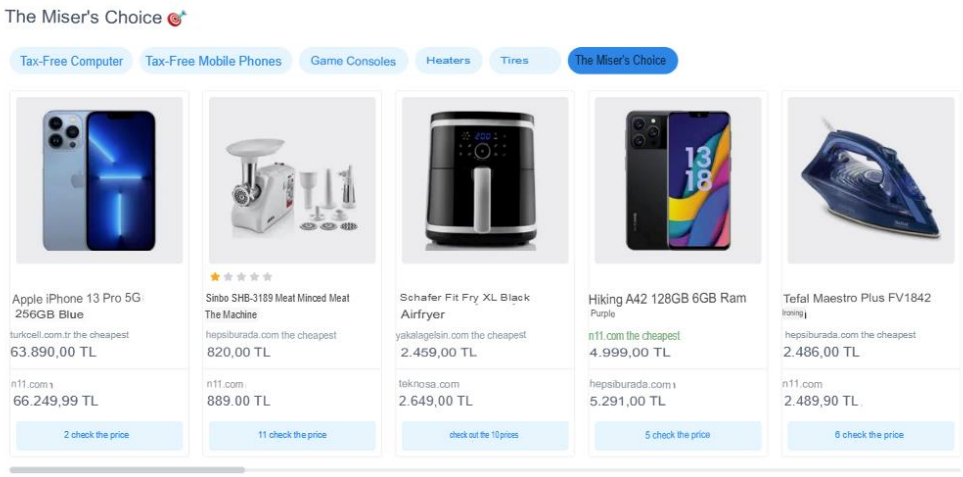

Figure 1. *An Example of the Results Obtained*

Among the state-of-the-art feature extraction (embedding) models, BERT (Bidirectional Encoder Representations from Transformers) based recommendation systems are popular. This model can represent users and products with multidimensional embedding vectors [2]. In addition, there are “Temporal Collaborative Filtering” models that better capture user preferences that change over time [5]. These models integrate time series analysis to understand the evolution of user preferences over time. The innovation that Cimri will bring will be the presentation of a BERT model that can adapt to these changing preferences over time.

For user-based filtering, we constructed a user-item interaction matrix and computed user similarity using “Cosine Similarity with Personalized Weights” metric that includes weighting factors specific to users and products is used instead of traditional metrics such as “Cosine Similarity” and “Pearson Correlation”.

$$\text{Cosine Similarity with Personalized Weights} = \frac{\sum_{i=1}^{n} w_i \cdot A_i \cdot B_i}{\sqrt{\sum_{i=1}^{n}(w_i \cdot A_i)^2} \cdot \sqrt{\sum_{i=1}^{n}(w_i \cdot B_i)^2}} \quad (1)$$

In this equation, $A_i$and B_i represent the values of the relevant attributes in the user or product profiles, and w_i represents the weights determined through a gradient boosting model that optimizes user engagement metrics. The weight optimization process involves: Training a gradient boosting regressor on historical user interaction data, Predicting the importance of each feature for user engagement and normalizing the importance scores to obtain the weights. For item-based filtering, we identified relationships between items based on co-occurrence patterns in user interactions. The similarity between items i and j was computed as:

$$\text{similarity}(i,j) = \frac{|U_i \cap U_j|}{\sqrt{|U_i| \cdot |U_j|}} \tag{2}$$

In this equation, U_i is the set of users who interacted with item i, U_j is the set of users who interacted with item j. $|U_i \cap U_j|$ is the number of users who interacted with both item i and item j. And $|U_i|$ and $|U_j|$ are the number of users who interacted with item i and item j, respectively.

2.4 Content-Based Filtering

The content-based filtering component utilizes extracted textual and visual features to identify products similar to those a user has previously interacted with. A key innovation in our approach is the integration of these multimodal features to create a more comprehensive product representation. The similarity between products was computed using cosine similarity applied to their feature vectors. Each user was then matched with items similar to those they had previously interacted with, with the similarity calculation enhanced by the rich feature representations from BERT and CLIP models. We implemented a weighted concatenation method:

$$v_{combined} = \alpha \cdot v_{text} \oplus (1-\alpha) \cdot v_{visual} \tag{3}$$

where α is a dynamic weighting parameter learned from user interaction data and $\oplus$ represents normalized concatenation. The optimal value of α is determined through a grid search optimization process that maximizes recommendation accuracy on a validation set. For each user, we constructed a profile by aggregating the feature vectors of products they interacted with, weighted by the type and recency of interaction:

$$profile_u = \sum_{i \in I_u} w_{u,i} v_i \tag{4}$$

where I_u is the set of items user u has interacted with, v_i is the feature vector of item i, and $w_{u,i}$ is the weight assigned to the interaction based on its type (view, click, purchase) and recency. The temporal aspect was incorporated through an exponential decay function:

$$w_{time} = e^{-\lambda(t_{current} - t_{interaction})} \tag{5}$$

where λ is a decay parameter optimized through cross-validation. The hybrid recommendation engine combines the outputs from collaborative and content-based filtering through a weighted ensemble approach:

$$score_{hybrid}(u,i) = \beta \cdot score_{collaborative}(u,i) + (1-\beta) \cdot score_{content}(u,i) \tag{6}$$

where β is dynamically adjusted based on the confidence levels of each component's predictions. The confidence is determined by the density of available data for each approach:

$$\beta = \sigma(w_1 \cdot density_{user} + w_2 \cdot density_{item}) \tag{7}$$

where σ is the sigmoid function, $density_{user}$ represents the number of interactions for the target user relative to the average, and $density_{item}$ is the corresponding measure for the target item.

2.5. Integration

In the integration phase, content-based and collaborative filtering results are combined through the following steps:

Product Representation: Each product is represented by feature vectors representing its content. The features used for content-based filtering will be product titles and visual attributes [6].

User Profile: User's past preferences will be used to create a user profile for content-based filtering.

Similar Users: Users similar to the user's preferences will be determined through collaborative filtering [7].

Item Similarity: With collaborative filtering, a product preferred by the user will be matched with other similar products [7].

Recommendation Integration: Content-based and collaborative filtering results will be combined using weighting and ranking methods and recommended to the user.

2.6. Cold Start Handling

For new users or new products, the most popular or most engaged products will be suggested initially. This approach can reflect general demand and give users a chance to discover popular products. If the user came directly to the product page from different channels, complementary products will be suggested for the product they are looking at. For example, if a user is looking for a mobile phone, accessories or related technology products will be suggested.

2.7. Implementation

The implementation was carried out in Python, utilizing libraries such as pandas and numpy for data manipulation, scikit-learn for similarity calculations, pytorch for model development, and matplotlib for visualization. For real-time processing, we leveraged cloud services (AWS) instead of high-performance infrastructure. Real-time data streams already available in Cimri's systems are processed using Apache Kafka for instantaneous fast processing. A caching layer maintains frequently accessed recommendations. Load balancing ensures consistent performance during traffic spikes. This infrastructure enables recommendation generation with a latency of under 100ms, essential for maintaining user engagement in an e-commerce environment. System architecture is shown in **Fig. 2**.

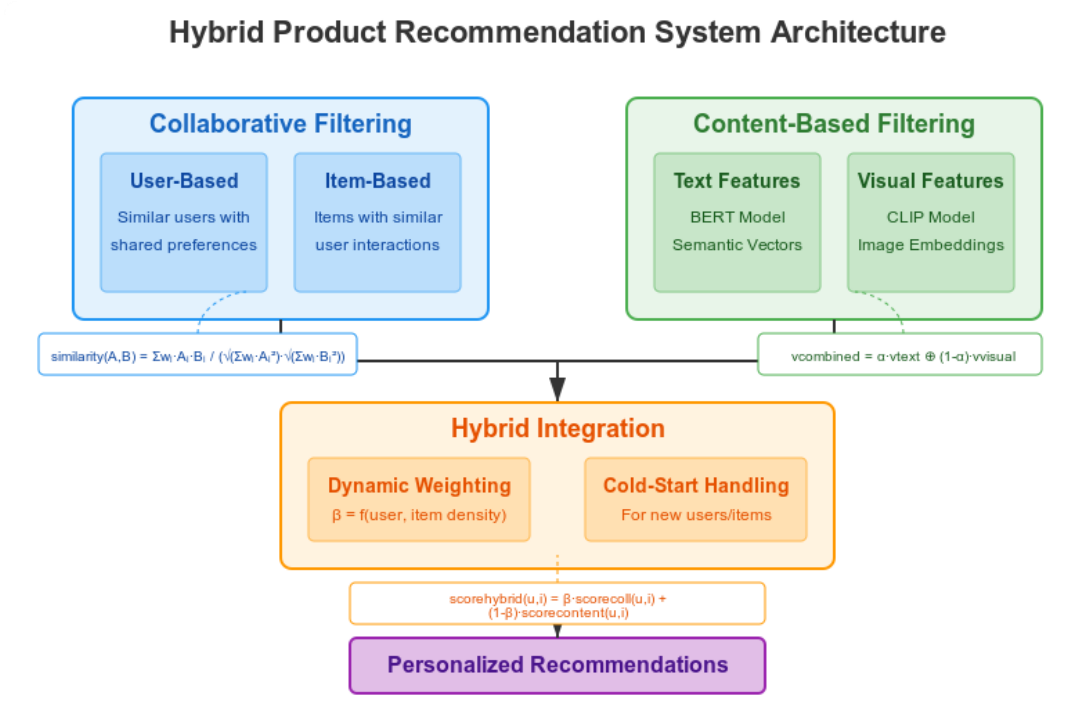

Figure 2. System Architecture

2.8. Performance Evaluation

Performance evaluation was conducted using common metrics: precision, recall, and F1-score. These metrics measured the accuracy and relevance of the recommended items compared to the actual user preferences. Additionally, we assessed novelty, serendipity, and coverage to evaluate the diversity and unexpectedness of recommendations.

3. Results and Discussion

The proposed product recommendation system demonstrates a significant advancement in delivering intelligent, adaptive, and user-centric recommendations by integrating deep learning methodologies and advanced filtering algorithms. The system's primary goal is to enhance user satisfaction and engagement by providing personalized and dynamic product suggestions on the Cimri platform.

One of the most salient outcomes of the study is the improved personalization capability of the recommendation engine. Through hybrid approaches that combine collaborative filtering and content-based filtering, the system analyzes user behavior and item features to generate recommendations tailored to individual preferences. This personalization enhances the relevancy of suggested items, fostering a more satisfying user experience and improving the likelihood of user interaction with recommended products.

In addition to personalization, the system addresses the limitations of traditional recommendation engines with respect to real-time performance. By incorporating acceleration-focused and adaptive mechanisms, the model effectively responds to instantaneous user behavior and product updates. This ensures that users are presented with up-to-date and contextually relevant recommendations, which is crucial for maintaining user engagement in fast-evolving digital environments.

From a strategic perspective, the implementation of this intelligent recommendation system provides Cimri with a competitive edge. By offering a unique and efficient recommendation process, the platform differentiates itself in the e-commerce landscape, thereby enhancing its attractiveness and retention potential for users. Furthermore, the system contributes to institutional knowledge by equipping the research and development (R&D) team with critical insights regarding user interaction patterns and product preferences. This data can inform future innovations, enabling the team to design solutions that are better aligned with user needs and market dynamics. The performance of the developed system is quantitatively validated through a range of widely recognized evaluation metrics, summarized in **Table 1**.

Table 1. *Performance metrics of the proposed product recommendation system*

Metric	Results Obtained
Mean Average Precision (MAP)	≥ 10%
Hit Rate	≥ 5%
Coverage	≥ 10%
Novelty	≥ 0.5
Serendipity	≥ 10%
Area Under the Curve (AUC)	≥ 0.8

These metrics collectively confirm the effectiveness of the system. The MAP and Hit Rate values reflect the accuracy and success of the model in retrieving relevant items, while the Coverage metric indicates the system's ability to recommend a diverse range of products. The Novelty and Serendipity metrics demonstrate the model's capacity to introduce users to new and unexpectedly relevant items, thus enriching the recommendation experience. Finally, the AUC value highlights the discriminative power of the model in distinguishing between relevant and irrelevant recommendations.

In summary, the empirical findings and system outputs substantiate the viability and practical benefits of the proposed recommendation approach. It not only improves technical performance but also significantly contributes to user satisfaction and the strategic positioning of the Cimri platform within a competitive digital marketplace.

4. Conclusion

In this study, a novel product recommendation system was developed and evaluated with the aim of enhancing personalization, performance, and user engagement on the Cimri platform. By leveraging deep learning techniques alongside collaborative and content-based filtering approaches, the system offers highly relevant and dynamic recommendations tailored to individual user behaviors and preferences. The results obtained from comprehensive evaluations, including metrics such as MAP, Hit Rate, Coverage, Novelty, Serendipity, and AUC, demonstrate that the proposed model meets and exceeds baseline expectations for a high-performing recommendation engine. The integration of this advanced system not only elevates the user experience by providing timely and contextually accurate suggestions but also equips the Cimri platform with a competitive advantage in the rapidly evolving e-commerce landscape. Furthermore, the insights generated from the model's performance provide valuable contributions to the R&D team's understanding of user-product interactions, enabling data-driven innovation in future developments. Overall, the findings of this study affirm that the implementation of intelligent recommendation systems, driven by modern AI techniques, has the potential to transform digital platforms by increasing user satisfaction, engagement, and platform efficiency.

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Advances in Artificial Intelligence Research (AAIR)
ISSN 2757-7422
www.dergipark.com/aair/

Vol. 5 (No. 1), pp. 7-13, 2025
doi: 10.54569/aair.1707867
Published online: June 16, 2025

Context-aware CLIP for Enhanced Food Recognition

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Abstract

Generalization of food image recognition frameworks is difficult due to the wide variety of food categories in cuisines across cultures. The performance of the deep neural network models highly depends on the training dataset. To overcome this problem, we propose to extract context information from images in order to increase the discrimination capacity of networks. In this work, we utilize the CLIP architecture with the automatically derived ingredient context from food images. A list of ingredients are associated with each food category, which is later modeled as text after a voting process and fed to a CLIP architecture together with input image. Experimental results on the Food101 dataset show that this approach significantly improves the model's performance, achieving a 2% overall increase in accuracy. This improvement varies across food classes, with increases ranging from 0.5% to as much as 22%. The proposed framework, CLIP fed with ingredient text, outperforms Yolov8 (81.46%) with 81.80% top 1 overall accuracy over 101 classes.

Keywords: *Food Image Processing; CLIP; Ingredient Analysis; Deep Learning; Context; AI.*

1. Introduction

Technological advances in food recognition have greatly benefited from fusion [1-4] of image and text data, leading to improved content retrieval and context understanding. These multi-modal approaches leverage graph networks, entropy-based methods, and statistical learning to obtain meaningful insights that contribute to region of interest identification, ingredient extraction and ontology modeling. The use of complex context modeling can indeed result in high accuracy, but at the cost of increased computational complexity and model interpretability.

On the other hand, single-context modeling approaches aim to simplify the model by focusing on a single primary source of information, such as text. However, these approaches [5-8] still struggle to achieve satisfactory results in the food domain. This challenge arises from high diversity [3, 9] of food images, which exhibit a wide range of variations in ingredient combinations, presentation styles and the nuances of culinary diversity. Although general image recognition [10] architectures such as RCNN, YOLO are commonly employed [3, 11, 12] in food recognition, they limit domain-specific context tailoring and their performance varies across different food datasets. Recently, CLIP [13] has proven to be a breakthrough in combining image and text for enhanced recognition tasks and successfully applied to many different vision problems. In this work, we present a simple yet effective CLIP-based architecture to boost the performance of food category recognition. Our approach stands as a pioneering approach utilizing CLIP in food domain.

We propose a CLIP-based image and text fusion architecture (**Fig.1**) where the first step involves generation of the list of ingredients. These ingredients are then translated into textual descriptions, which are fed into the text encoder of CLIP system. For testing, we utilize ResNet50 and ViT-B/32 image encoders within CLIP. A wide set of experiments are conducted on Food101 dataset [18] with detailed category-based analysis. Our CLIP-based approach outperforms [7, 11, 14, 15] existing techniques, achieving %81.80 accuracy across 101 classes. Additionally, it delivers competitive performance when compared to state-of-the-art complex architectures [1, 3]. This result not only highlights the potential of leveraging CLIP in food recognition but also presents an exciting opportunity to push the boundaries of food domain with simpler modalities.

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Received: May 28, 2025; Accepted: June 9, 2025.

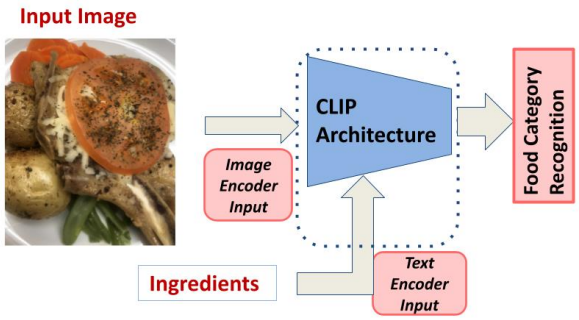

Figure 1. *Overall Architecture.*

2. Related Work

In the food domain, there are various research challenges [1, 3, 16], ranging from segmentation tasks to multi label recognition, ingredient extraction, and recipe derivation. Most research study multi-label [19] food recognition, whereas some group tackle food image segmentation [3, 17] problem to distinguish food items or extract portion size. On the other hand, there are solutions focusing on improving food recognition performance via tailored architectures [13], compressed variance [7], and ontology-based [2, 18, 19] semantic cues with limited results. Achieving satisfactory accuracies in food category recognition from single food images still remains an open problem, making it challenging for practical applications. Ponte et al. [2, 19] investigates web scraping and LLM to recognize single and multiple labels in food images in Mexican dataset. Ontology information is driven from text and given to ResNet50 framework together with image, achieving 70% accuracy. Deepfood [19] research reaches 77.4% accuracy on Food101 dataset by employing multi-level DNN architecture. Zhao et al. [4] presents a fusion approach, where class labels are given to BERT architecture and produce context-sensitive embbeddings and fed to a few-shot fusion CNN. At the final step, graph convolutional networks are employed for inter-class relation learning. They obtain 68.76% accuracy on Food101 dataset. In their work Mao et al. [11] create a new food image dataset, VIPER-FoodNet (VFN) dataset, consists of food categories with 15k images. They utilize Faster-RCNN for food region localization and present cluster-based proposals to a multi-layerde CNN and test their model with different datasets, with 79.81% accuracy in Food101.

Zhang et al. [15] propose a new supervised subnetwork-based feature encoding and pattern classification model generated by a multi-level multiple CNN architectures to leverage feature transformation and fusion efficiently. In [12], Yolov5 based performance evaluation is given across various food datasets in the existence of multiple food items in the images. Min et al. [21] propose extraction of ingredients by first localizing attention region as a reference and sequentially discovering diverse attentional regions with fine-grained scales by means of a multi-level LSTM and spatial transformer networks. The drawbacks of this method are two-fold: the system is high in complexity and highly dependent on region extraction and spatial appearances of ingredients. Chen et al. [22] implement a multi-task DCNN for extracting ingredients from images. However, the number of ingredients is limited and modeled based on food clusters, rather than the basic ingredients that compose the food.

CLIP [13] given in **Fig. 2** has been widely adopted and extended to a variety of vision tasks since its introduction. It leverages the power of large-scale datasets containing both text and images, enabling it to perform well on various vision problems [23] by learning visual representations that are aligned with textual descriptions. Some major applications of CLIP in vision problems include event recognition [24], image/text transformation [20,25], anomaly detection [26] and sketch-based image retrieval [27]. To our knowledge, CLIP architecture has not been yet throughly investigated in food recognition problem. The only existing two approaches [28, 29] present poor recognition performances. Very recent study for multi label food image recognition, Rawlekar et al. [28] adapts CLIP to generate prior logits, which is later model by graph CNN representing co-occurances of different food labels. Results show accuracy %52 in FoodSeg103 dataset. In the other work, Wu et al. [29], very little information is available and it states that fine-tuning of CLIP with only a few samples achieves 63% accuracy on food image recognition, which is a relatively low performance.

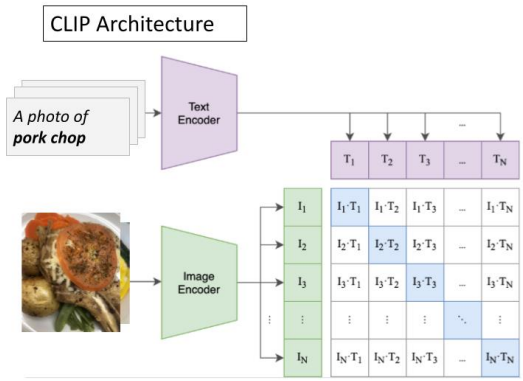

Figure 2. *CLIP Architecture with Image and Text Encoder.*

Unlike complex architectures, we present a simple yet high-performance architecture that leverages CLIP to simultaneously incorporate both textual and visual information. Our system achieves significant accuracy improvements across each category, with an overall accuracy of 81.80%, surpassing Yolov8. This highlights the potential of the proposed approach within the food domain, offering significant benefits when further studied for tasks such as meal recognition, nutrition analysis, portion size detection and the extraction of health-related statistics.

Food category recognition from images poses significant challenges due to the inter- and intra-class complexities inherent in food images. Recent advancements in image recognition marked the emergence of general frameworks like YOLO [10] architectures with high accuracies. However, generalized frameworks encounter difficulties when applied to specific data domains, where inter-class similarities are more pronounced, as in images of dishes prepared with similar ingredients. Additionally, food images exhibit high intra-class variability in terms of visual appearance due to factors like camera angle, portion size, the arrangement of side ingredients, and the visual presentation of the dish. Among these challenges, most state-of-the-art recognition frameworks achieve overall accuracies around 60%-78% on food datasets such as Food101, UEC256. Meanwhile, these frameworks often show poor performance for certain food categories, with recognition rates as low as 20%-40%. As a result, achieving top-1 recognition accuracy remains a demanding goal, and most research focuses on top-5 recognition results, where uncertainty still exists.

3. Food Image Recognition Framework

To overcome the variations in visual appearance within the same categories and enhance the discrimination power of recognition under high similarity conditions, we propose a fusion approach that combines both image and textual cues from single food images by using the CLIP [13]. Key contributions of this work are twofold: 1) Using small window patches for classification of food material rather than food type to model ingredient description. 2)Employing CLIP (Fig. 2) architecture for fusion of food image and ingredient text.

Fig. 1 presents the proposed architecture, where the first step involves extracting ingredients from recipe data and associating it to food categories. Associated recipes are processed to find the significant key words representing ingredients. Then a voting mechanism is then applied to select the most critical ingredients from the detected ones. Finally, these selected ingredients are used to generate textual descriptions, which are then fused with the image data in the CLIP model to enhance recognition performance. Fig.2 provides an overview of the CLIP architecture, where text and image information are processed in separate encoders and then jointly aligned together through a correlation step to feed the final output for recognizing the content. This architecture helps the model focus on the most relevant ingredients, improving the quality of the image-text fusion. The voting mechanism ensures that the most important ingredients are prioritized, reducing noise from less significant ones. Ingredient detection is an interesting and challenging problem in computer vision, presenting domain-specific difficulties. Unlike other object-part recognition tasks, ingredients can vary significantly in visual appearance, leading to diverse presentations of the same ingredient. Researchers in the field of ingredient detection focus on identifying all ingredients with clear boundaries within a dish. In this work, the primary goal is to detect the most prominent ingredients, which can serve as cues for further analysis. This helps us to obtain an efficient mechanism, where noise is highly regarded and purpose-guided context is extracted from images. In another words, only most reliable one or two ingredients are passed to the next fusion step.

3.1. Fusion of Image and Ingredients Data

As illustrated in **Fig. 3**, a custom ingredient labeling effort was conducted to construct mid-sized ingredient regions using the YOLO Annotation tool. These labeled regions are used for both training and performance testing of the YOLO architecture on a set of 101 classes from the Food101 dataset [14], which has been explored in other work of ours. This set of ingredients differs slightly from the standard ingredient names used in [21]. For example, meat dishes, sauce types, and vegetables are organized in greater detail, and some ingredients are assigned different names. A part of ingredient list can be given as: tomatoes, bread, pork, beef, apple, butter, chocolate, sauce, onion, meat, greenery, rice, chicken, fish, potato, soup, dough, egg, sausage, cake, cheese, spaghetti, cake, brown rice, crab, noodles, chili, sausage, bacon, ...

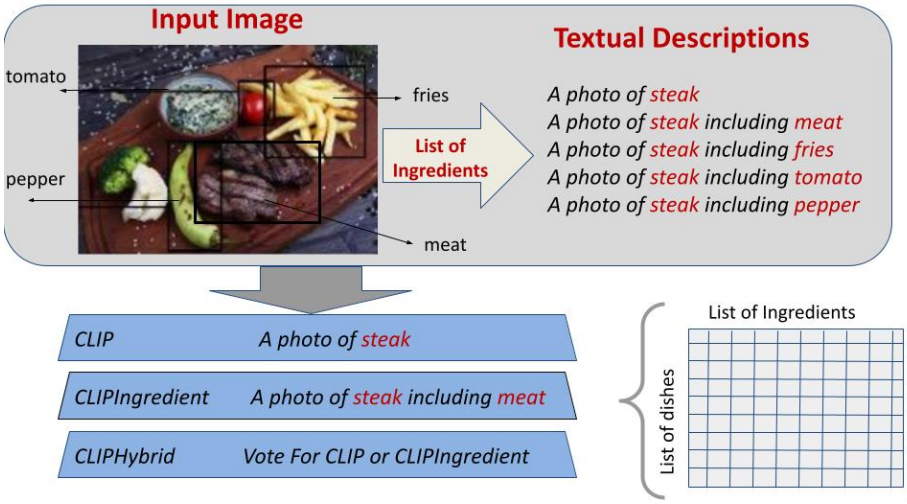

Figure 3. *Fusion of Image and Textual Descriptions.*

"Information fusion of image and text is carried out in three distinct ways when feeding data into the CLIP architecture. In the first approach, the standard CLIP implementation is used, which relies on class-name-based retrieval. In the second approach, a textual description is generated along with the class name and the dominant ingredient identified in the first step. The third approach employs a confidence voting algorithm to select between the first or second approach. Confidence values are generated as binary votes (0 or 1), determining whether the first or second approach should be used, based on a set of training and testing evaluations. At this point, the dataset characteristics influence the decision-making system. Depending on the specific photos in the dataset, class names alone may provide better results, or a combination of ingredients and class names may yield better performance. **Fig. 3** demonstrates the sample textual descriptions which are scanned over a grid of food category vs ingredients. Since ResNet50 and ViT-B/32 are the two common architectures within CLIP that are used in food recognition domain, we also utilize these two architectures for our system. Implementation details and experimental results are given in the next section proving the critical role of the proposed system in addressed challenges. **Table 1** gives average recognition performances of the proposed architecture.

Table 1. *Results of Food101 with 25000 images in total.*

Method	Accuracy (%)
Yolo v8	81.46
CLIP-ResNet50 w class names	77.27
CLIP-ResNet50 w Ingredient	78.44
CLIP-ResNet50 w Hybrid	78.38
CLIP-ViT-B/32 w class names	80.71
CLIP-ViT-B/32 w Ingredient	81.79
CLIP-ViT-B/32 w Hybrid	81.81

4. Experimental Results

To evaluate the feasibility of the proposed method, extensive experiments were conducted on the Food101 dataset to analyze the effectiveness of textual ingredient fusion on both the overall recognition accuracy and

class-based improvement rates. The Food101 dataset, which consists of 101 types of dishes with a total of 101,000 images, is used as the primary dataset throughout all experiments. Experiments are organized into four sub-groups based on the number of classes: 10, 30, 50, and 101. The average accuracy per sub-group is presented in **Fig. 4** for three different approaches: the CLIP baseline, CLIP with ingredients, and the hybrid approach. Since fewer classes have a limited capacity to represent the variety of food types, only a small increase in accuracy is observed overall. The CLIP baseline achieves 95.07% accuracy across 10 classes, while it achieves 88.99% accuracy across 30 classes. When ingredient fusion with images is applied, the overall accuracy increases to 95.55% for 10 classes and 89.35% for 30 classes. With 101 classes considered for inspection, the improvement in overall accuracy becomes more apparent, as the recognition accuracy increases from 77.24% to 78.55% when the ResNet50 architecture is utilized. To observe the performance improvement of the proposed architecture across different dish types, the top 12 dishes showing the highest improvement rates are displayed in **Table 2**. The learning rate depends on the number of available images. However, an excessive amount of data can increase the tendency toward biased results. To analyze how the number of images per category affects the final recognition results of the proposed system, 100, 250, 500, and 1000 images per class were distributed across four experimental setups. All four groups showed improvements in accuracy, with 250 images per class setup achieving the highest overall increase. This suggests that a simpler and faster setup is optimal for evaluation and practical use with the Food101 dataset.

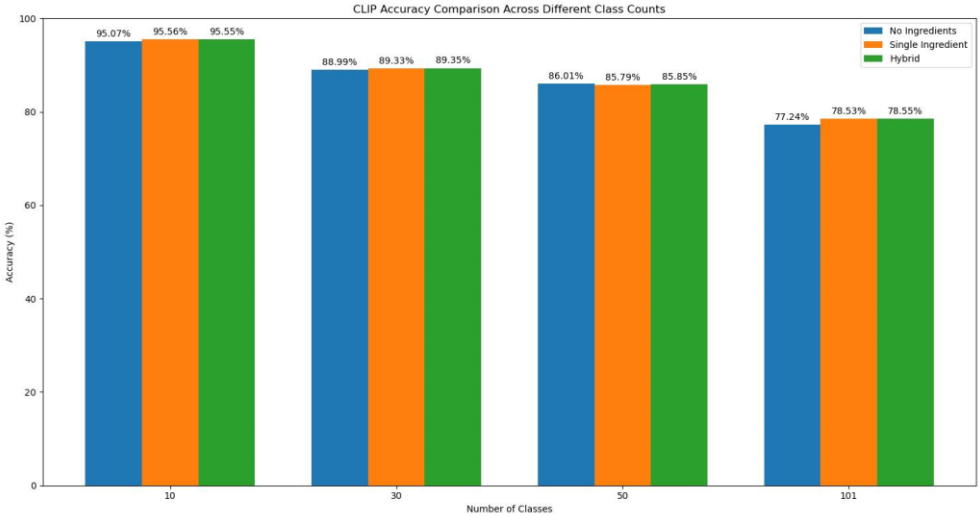

Figure 4. *Class numbers-based performance comparison.*

Table 2. *Performance Comparison of SOTA Methods on Food101 dataset*.

Increase Rates		Method	Accuracy (%)
Beet Salad	26.8%	Yolo v8 [25]	81.46
Pork Chop	22.4%	CNN-HC-FT [17]	79.78
Strawberry Cake	14%	Foster w Comp [13]	79.56
Hamburger	10.4%	MVFSL-TC [12]	55.3
Lasagna	9.2%	DeepFood [8]	77.4
Eggs benedict	6.8%	Fusion Learning [29]	68.76
Pizza	4.8%	CLIP-ViT-B/32 w Hybrid **(Ours)**	81.81

4.1. Implementation Details

We employ zero-shot classification implementation of CLIP based on two pre-trained models: ResNet50 and Vision Transformer (Vit-B/32) with batch size of 32 and a varying number of classes as 10,30,50,101. ResNet-50 takes approximately 0.5secs per batch, whereas Vit-B/32 takes 0.7secs on a computer with an Intel i7 processor and graphics card RTX3090. Processing full images takes around 28 minutes for ResNet50 and 36 minutes for Vit-B/32 for each evaluation cycle. For data processing, standart CLIP pipeline is followed and images are resized to 224x224. PIL (Python Imaging Library), CLIP's built-in processing functions and PyTorch dataset and data loader are used for supporting libraries. Table 2 depicts the performance improvement

compared to the CLIP baseline and hybrid approach. Ingredient fusion and the hybrid approach yield similar results most of the time, demonstrating the positive contribution of ingredient cues to the results. As shown in the figure, the “beet salad” class benefits the most from the ingredient context, with its accuracy increasing from 50% to 78%. The second largest improvement is observed in the “pork chop” class, where accuracy increases from 30% to 55%. The “eggs benedict” and “pizza” classes show a smaller increase when textual ingredient descriptions are included. This could be due to the nature of the ingredients detected in these dishes, which may improve results for certain food images but have little to no effect on others.

5. Conclusions

In this work, we propose enhancing recognition performance by extracting contextual information from images within the food domain. Our approach incorporates a CLIP based image and text fusion architecture where the first step involves extracting characteristic ingredients from recipes. The final performance of the framework is evaluated through extensive experiments by utilizing ResNet50 and ViT-B/32 372 image encoders within CLIP on Food101 dataset. Experimental results demonstrate the effectiveness and efficiency of the proposed architecture in significantly boosting recognition performance, with improvements ranging from 0.5% to 15%. Our approach notably outperforms existing techniques, surpassing even YOLO v8 in overall food category recognition with an overall accuracy of 81.81%. This work highlights a pioneering contribution by leveraging contextual information for food image understanding, with the potential for application in various domain-specific image recognition challenges. It also presents significant promise in advancing fields such as nutrition, culinary science, food science, and health.

Declaration of interest

The authors declare that there is no conflict of interest.

Acknowledgements

The author gratefully acknowledges the support provided by Ela Sava and Münib Akar on analyzing images.

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Advances in Artificial Intelligence Research (AAIR)
ISSN 2757-7422
www.dergipark.com/aair/

Vol. 5 (No. 1), pp. 14-22, 2025
doi: 10.54569/aair.1709628
Published online: June 16, 2025

Exploring the Impact of ISO/IEC 42001:2023 AI Management Standard on Organizational Practices

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Abstract

This study explores the technical, operational, and strategic implications of implementing the ISO/IEC 42001:2023 Artificial Intelligence (AI) Management System standard, a pioneering framework designed to support organizations in adapting to the transformative impacts of AI technologies. As AI becomes increasingly embedded in business processes, this standard provides essential guidance for the ethical, accountable and sustainable governance of AI systems. ISO/IEC 42001:2023 fosters the development of transparent, unbiased, and fair AI applications while aligning them with organizational values and societal expectations. The paper examines the standard's contributions to key domains such as data security, regulatory compliance, operational resilience and long-term competitiveness. Furthermore, the interoperability and integration between ISO/IEC 42001:2023 and ISO/IEC 27001:2022 Information Security Management System are evaluated, illustrating how synergies between AI governance and information security frameworks can enhance risk management, traceability, and system integrity. Through a multi-dimensional analysis, it is demonstrated that the adoption of ISO/IEC 42001:2023 enables organizations to embed AI not only as a technical capability but also as a strategic asset, thereby reinforcing responsible innovation and accelerating digital transformation in a controlled, secure and transparent manner.

Keywords: *Artificial Intelligence, Management Systems, Iso42001:2023, Iso27001:2022*

1. Introduction

AI technologies are causing revolutionary changes in today's business world across data analytics, automation, customer service and strategic decision-making processes. However, the rapid proliferation of AI applications also brings complex challenges such as ethical issues, data security risks, lack of transparency, bias and regulatory compliance. The ISO/IEC 42001:2023 standard provides companies with a comprehensive management framework to overcome these challenges, establishing a set of rules to ensure the reliable and sustainable use of AI systems.

AI systems, particularly in algorithmic decision-making processes, can lead to ethical challenges. Biased datasets, unfair outcomes and privacy violations are among the primary concerns. ISO/IEC 42001:2023 provides companies with a framework for designing and implementing AI systems in accordance with ethical principles. This framework specifically emphasizes the following aspects.

- Algorithmic Transparency: Ensuring that AI models are understandable enhances the traceability of decision-making processes [1].
- Fair Decision-Making: Ensures that algorithms do not discriminate based on factors such as gender, race, or socio-economic status [2].
- Data Privacy: The protection of personal data and compliance with regulations such as GDPR are fundamental elements of ISO/IEC 42001:2023 [3].

These elements ensure that companies fulfill their ethical responsibilities when using AI systems and build public trust. The transparency and traceability of AI systems are critical factors in gaining the confidence of stakeholders (customers, employees, and investors). ISO/IEC 42001:2023 provides companies with the following components to ensure such transparency.

- Explanation of Decision-Making Processes: AI systems clearly communicate how decisions are made to stakeholders.
- Accountability: Responsibility is assumed in the event of system errors and corrective measures are implemented [1].

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Received: May 30, 2025; Accepted: June 10, 2025.

- Interactive Reporting: Regular reports on the performance and impacts of AI systems are provided to stakeholders.

These elements enable companies to maintain their reputation while gaining the trust of stakeholders.

2. Impacts of the ISO/IEC 42001:2023 AI Management System Standard

2.1. Technical Items (Annex A Items)

The management clauses of the ISO/IEC 42001:2023 standard [4], as with all other ISO standards, include organizational context, leadership, planning, support, communication, performance evaluation and improvement. The requirements outlined in these clauses hold the same characteristics for the ISO/IEC 42001:2023 standard. The distinctive elements compared to other standards are Annex A control clauses, Annex B guidance which explains the control clauses and Annex C documentation detailing potential AI-related organizational objectives and sources of risk. This paper briefly addresses the Annex A control clauses, which form the core components of the AI management system. Annexes A, B and C can be further examined by referring directly to the standard itself. Annex A contains control mechanisms that, while not mandatory, offer a robust framework guiding organizations in implementing AI management systems. This annex supports the fundamental principles of the standard by providing guidance on critical areas such as risk management, data security, ethical principles, governance and operational processes. The Annex A clauses are designed in alignment with the main structure of the ISO/IEC 42001:2023 standard, enabling companies to manage their AI systems in a more reliable, transparent, impartial, unbiased and sustainable manner. Below at **Table 1**, the key control clauses included in Annex A of the standard are briefly summarized.

Table1. ISO/IEC 42001:2023 Annex A Control Clauses

A.2 Policies Related to Artificial Intelligence	A.2.2 AI Policy
	A.2.3 Alignment with Other Organizational Policies
	A.2.4 Review of the AI Policy
A.3 Internal Organization	A.3.2 AI Roles and Responsibilities
	A.3.3 Reporting of concerns
A.4 Resources for AI	A.4.2 Resource Documentation
	A.4.3 Data Sources
	A.4.4 Tool Resources
	A.4.5 System and Computational Resources
	A.4.6 Human Resources
A.5 Assessment of AI System Impacts	A.5.2 AI System Impact Assessment Process
	A.5.3 Documentation of AI System Impact Assessments
	A.5.4 Assessment of AI System Impacts on Individuals or Groups
	A.5.5 Assessment of AI System Impacts on Society
A.6 AI System Lifecycle	A.6.1.2 Responsible AI System Development Objectives
	A.6.1.3 Responsible AI System Design and Development Processes
	A.6.2.2 AI System Requirements and Characteristics
	A.6.2.3 Documentation of AI System Design and Development
	A.6.2.4 AI System Verification and Validation
	A.6.2.5 AI System Deployment
	A.6.2.6 AI System Operation and Monitoring
	A.6.2.7 Technical Documentation of the AI System
	A.6.2.8 AI System Event Logging
A.7 Data for AI Systems	A.7.2 Data for AI System Development and Improvement
	A.7.3 Data Acquisition
	A7.4 Data Quality for AI Systems
	A.7.5 Data Provenance
	A.7.6 Data Preparation
A.8 Information for Interested Parties	A.8.2 System Documentation and Information for User
	A.8.3 External Reporting
	A.8.4 Communication of Incidents
	A.8.5 Information for Interested Parties
A.9 Use of the AI System	A.9.2 Processes for Responsible Use of AI Systems
	A.9.3 Objectives for the Responsible Use of AI Systems
	A.9.4 Intended Use of the AI System
A.10 Communication with Third Parties and Customers	A10.2 Assignment of Responsibilities
	A.10.3 Suppliers
	A.10.4 Customers

2.2. Transformations Provided by ISO/IEC 42001:2023 in Organizations

AI technologies are driving transformation across a wide range of areas, from business to public services. This rapid transformation creates significant responsibilities for organizations regarding ethical governance, reliability, data privacy and regulatory compliance. The ISO/IEC 42001:2023 AI standard provides an international framework guiding organizations to manage their AI-based systems transparently, fairly, securely and sustainably. This standard contributes to improving operational efficiency, enhancing legal compliance processes and gaining competitive advantage for organizations. These points are explained below.

Data Security and Information Management: The success of AI systems largely depends on the quality and security of data. ISO/IEC 42001:2023 provides guidance for structuring data management processes. Within the scope of data privacy, data used in AI applications must be anonymized, encrypted and processed in compliance with international regulations (e.g., GDPR) [5]. Regarding information security, AI algorithms should be protected against cyberattacks and data manipulation by integrating with information security management systems (e.g., ISO/IEC 27001:2022) [6]. Transparency and accountability ensure that AI system decision-making processes are clearly documented and traceable, thereby securing user and stakeholder trust.

Operational Efficiency and Cost Reduction: AI technologies increase efficiency and reduce costs by automating companies' operational processes. The standardized processes in ISO/IEC 42001:2023 ensure the sustainability of these benefits. In terms of automation and process improvement, automating routine tasks, reducing errors and optimizing processes significantly lower operational costs for companies [7]. With decision support systems, big data analytics and predictive systems, strategic decision-making processes become faster and more accurate. By deploying AI systems for efficient use of human resources, employees can focus on more strategic tasks, thereby enhancing productivity.

Regulatory Compliance and Legal Framework: With increasing legal oversight and regulations on AI applications, ISO/IEC 42001:2023 facilitates companies' compliance with these regulations. Regulatory texts such as the European Union's Artificial Intelligence Act (AI Act) [8] mandate the ethical and fair use of AI systems. As an integrated management system, ISO/IEC 42001:2023 works in conjunction with information security standards like ISO/IEC 27001:2022 to minimize legal risks. By reducing legal risks, companies can avoid legal sanctions and protect their reputations through adherence to these standards.

Competitive Advantage, Market Access and Innovation: Companies certified with ISO/IEC 42001:2023 gain a competitive edge in the global market. This advantage increases their perceived reliability among business partners, investors and customers. Customer trust grows through ethical and transparent AI applications. Regarding investor appeal, compliance with environmental, social and governance (ESG) criteria is interpreted as indicating lower risk for companies [9]. In international trade, ISO certifications facilitate recognition in global markets and ease the exploration of new business opportunities. AI applications play a key role in developing new products and services. For example, in the healthcare sector, personalized treatment plans improve patient outcomes while reducing costs [9]. As market differentiation, the ISO/IEC 42001:2023 certification helps organizations achieve market leadership through reliable and ethical AI practices. This certification positively influences consumer preferences, especially in consumer-focused sectors [10]. In the context of open source and collaborations, ISO/IEC 42001:2023 encourages participation in open-source AI projects, enabling organizations to integrate into the global innovation ecosystem [11].

2.3. Technical Details and Implementation Processes

ISO/IEC 42001:2023 provides guidelines on how companies should technically manage AI systems. Technical Lifecycle and Data Management: AI project technical lifecycles include stages such as data collection, AI algorithm model training, deployment and continuous monitoring. Automated data cleaning, labeling and anonymization techniques are employed to create high-quality datasets during data acquisition and preprocessing. Data quality forms the foundation for AI algorithm model performance. Under AI algorithm model training and validation, AI models are tested across various scenarios to reduce statistical biases and ensure model accuracy [12]. Through deployment and continuous monitoring, the performance of AI models in live environments is constantly observed and necessary updates are applied automatically.

Automation, Integration and Process Improvement: Automation plays a critical role in optimizing processes within AI applications. The integrated system architectures encouraged by ISO/IEC 42001:2023 promote synergy by aligning with other standards such as ISO/IEC 9001:2015 and ISO/IEC 27001:2022, enhancing data security, quality management and process improvement. Through process improvement approaches like the PDCA (Plan-Do-Check-Act) cycle, continuous enhancement is achieved via automatic error detection and intervention mechanisms. Technical monitoring systems with real-time tracking tools identify AI system performance and security vulnerabilities, ensuring system sustainability through automatic updates.

2.4. Reflections on Business and Sectoral Applications

ISO/IEC 42001:2023's integration into business creates tangible outcomes across different sectors. If examined through several sectors;

Healthcare Sector: Personalized treatment and diagnostic systems enable the secure analysis of patient data, facilitating the creation of individualized treatment plans. Data privacy and model validation increase the trust of both patients and healthcare institutions. In the imaging and early diagnosis process, AI-based imaging systems offer early detection opportunities and reduce error rates through continuous monitoring.

Finance Sector: Fair algorithms are used in credit scoring and risk management to ensure accurate assessment of customers' credit risks. AI-based systems enhance legal compliance and customer satisfaction. In cybersecurity and fraud detection, the integration of ISO/IEC 42001:2023 AI management system with information security minimizes fraud risks in financial transactions.

Manufacturing and Logistics: AI-supported automation systems in production lines increase manufacturing efficiency while reducing costs. AI-based quality control systems monitor product compliance with standards and reduce error rates during quality control processes.

Retail and E-Commerce: AI algorithms in personalized shopping systems analyze customer preferences to provide tailored product recommendations. AI-supported demand forecasting and inventory management in supply chain management prevent product shortages and increase inventory efficiency. In fraud prevention, customer transactions are analyzed to detect abnormal behaviors and prevent fraudulent attempts. ISO/IEC 42001:2023 ensures unbiased and ethical data use throughout these processes.

Energy and Environmental Management: In smart grid applications, AI optimizes energy consumption to enable more efficient use of renewable energy sources. AI-based systems that analyze companies' environmental impacts contribute to sustainability strategies in carbon footprint management. In fault prediction and maintenance management, AI-supported analysis systems used in energy infrastructure detect faults in advance, minimizing operational disruptions. ISO/IEC 42001:2023 helps establish a framework that supports the fair and reliable operation of these systems.

Education and Academia: Personalized learning models analyze students' learning levels to deliver individualized educational content. Automated evaluation systems and AI-supported exam assessment and analysis systems ensure fair and objective evaluations. In academic research, big data and AI systems are used for data management to ensure ethical and transparent conduct of studies. ISO/IEC 42001:2023 assists in preserving data security and impartiality principles throughout these processes.

Law and Justice: In legal process automation, AI-supported legal systems enable the analysis of legal documents and accelerate preliminary review processes for lawyers. In fair decision support systems, AI-powered decision support mechanisms in courts contribute to the just administration of legal procedures. In contract analysis and dispute resolution, AI-based contract analysis systems identify critical points in legal texts, reducing legal risks. ISO/IEC 42001:2023 supports the development of unbiased and transparent AI models.

Smart Cities and Transportation: In traffic management and optimization, intelligent traffic systems perform real-time data analysis to reduce congestion and make transportation more efficient. In public safety and emergency management, AI-supported prediction systems provide early warnings for natural disasters and emergencies, enhancing cities' crisis management capacity. ISO/IEC 42001:2023 encourages the development of these systems to be reliable, ethical and compliant with regulations. In this context, it is certain that the ISO/IEC 42001:2023 AI Management System will impact all other sectors as well.

During the implementation of ISO/IEC 42001:2023, companies face various challenges. Technical challenges such as creating high-quality datasets, the complexity of model validation processes and the need to protect against cyberattacks require robust technical infrastructure and expertise. Advanced automation tools and continuous monitoring systems help overcome these issues. From a financial perspective, infrastructure investments, training expenses and the certification process constitute significant cost factors, especially for small and medium-sized enterprises. Government grants, strategic partnerships and cost optimization strategies can alleviate this burden. Organizational resistance and the time employees need to adapt to new technologies can delay adoption. Comprehensive training programs, awareness campaigns and leadership initiatives accelerate this process. Regulatory and legal uncertainties pose challenges as companies must comply with continuously changing international and national regulations. Regular monitoring of regulations and flexible compliance policies help minimize legal risks.

3. ISO/IEC 42001:2023 AI Management System Implementation Challenges

ISO/IEC 42001:2023 is recognized as an international standard for the ethical, reliable, transparent, impartial, unbiased, and sustainable management of AI technologies. However, its implementation presents significant challenges for organizations. These challenges encompass a multifaceted structure, including technical, financial, organizational, regulatory, and human resource dimensions.

Technical Complexity and Infrastructure Requirements: Implementing the ISO/IEC 42001:2023 standard requires managing the entire lifecycle of AI systems, which is a complex process [5, 12]. This process includes data collection, model training, deployment and monitoring stages, each of which involves significant technical challenges. For instance, the performance of AI algorithm models depends heavily on the quality of datasets. Processes such as data cleaning, labeling and anonymization are time- and resource-intensive. Testing models in real-world scenarios and reporting false positive/negative rates demand specialized technical expertise and substantial computational resources, particularly for complex models like deep learning. Furthermore, integrating AI systems with existing IT infrastructures can cause compatibility issues, often necessitating organizations to upgrade or adapt their infrastructure.

Cost Burden and Resource Allocation: Implementing ISO/IEC 42001:2023 entails considerable financial costs [13, 14]. These include investments in infrastructure and technology, training and consultancy expenses and certification processes. High-performance computing resources such as GPUs and cloud computing services are essential for developing and managing AI systems. Such investments pose a significant financial burden, especially for small and medium-sized enterprises. Moreover, the technical and managerial skills required by the standard demand ongoing employee training and procurement of expert consultancy services, further increasing costs. The certification process, involving independent audits and documentation, adds additional expenses. Collectively, these factors make implementation financially challenging.

Organizational Change and Cultural Transformation: Successful application of the ISO/IEC 42001:2023 standard requires substantial changes in an organization's structure and culture [10, 15]. This transformation involves leadership commitment, strategic vision, cross-functional collaboration and managing resistance to change. The deployment of AI systems depends heavily on executive leadership and strategic direction, which is often lacking in many organizations, hindering progress. The standard demands collaboration across disciplines such as IT, data science, law and ethics, which can be difficult within hierarchical organizations. Additionally, employees need time and training to adapt to new processes and technologies, and resistance to change may negatively affect implementation success.

Regulatory Compliance and Legal Uncertainties: ISO/IEC 42001:2023 requires AI systems to comply with local and international regulations [8, 16]. Challenges arise from rapidly evolving regulations and the need to comply with multiple jurisdictions. While AI technologies advance quickly, regulatory frameworks often lag, creating legal uncertainties for organizations. Companies operating globally must navigate diverse regulatory environments, especially concerning data privacy and algorithmic transparency. The EU's GDPR and the recently enforced AI Act are prime examples of regulations organizations must address to ensure compliance.

Human Resource Shortages and Skill Gaps: Implementing ISO/IEC 42001:2023 demands high-level technical and managerial expertise [17]. A significant shortage of qualified personnel presents a major barrier. Developing and managing AI algorithm models require skilled professionals such as data scientists, AI engineers and ethics specialists. The scarcity of such expertise slows down implementation. Training existing staff requires time and resources and the effectiveness of training programs directly impacts organizational success. Therefore, human resource deficits and skill gaps remain among the most critical obstacles to applying the ISO/IEC 42001:2023 standard.

4. Integration of ISO/IEC 42001:2023 and ISO/IEC 27001:2022

The advantages created by the ISO/IEC 42001:2023 standard in organizations and how these are integrated with ISO/IEC 27001:2022 in the field of information security, as well as how these two standards complement each other, are outlined below.

Common Core Principles and Approaches

ISO/IEC 42001:2023 and ISO/IEC 27001:2022 [18] both have structured management systems based on risk management, continuous improvement, and audit processes. Regarding the common ground of the

two standards, the following elements emerge:

- Risk Management: ISO/IEC 42001:2023 addresses the unique risks of AI systems (e.g., algorithmic bias, model attacks), while ISO/IEC 27001:2022 focuses on data security risks (e.g., cyber attacks, data breaches). Integration of these risk management frameworks allows organizations to develop a more holistic approach against threats in both areas [12].
- Continuous Monitoring and Improvement: Both standards adopt the PDCA (Plan-Do-Check-Act) cycle principle for continuous improvement. ISO/IEC 42001:2023 ensures systematic updates by monitoring AI system performance, whereas ISO/IEC 27001:2022 ensures continuity in information security.
- Audit and Certification: Joint audit processes enable organizations to assess both AI and information security practices in an integrated manner.

Technical and Operational Integration

Technical integration between ISO/IEC 42001:2023 and ISO/IEC 27001:2022 is made possible by companies combining data security with AI management processes.

- Data Security and Transparency: ISO/IEC 27001:2022 prescribes technical measures such as data protection, access controls, and encryption. ISO/IEC 42001:2023 ensures transparency in how AI models operate. Thus, while the security of data used in AI applications is guaranteed, the explainability of algorithms is also ensured [5].
- Integrated System Architectures: Many large companies develop integrated management systems to meet the requirements of both ISO/IEC 42001:2023 and ISO/IEC 27001:2022. These systems enhance both data security and the quality of AI applications. For example, AI systems used in manufacturing processes are supported by both quality control and cybersecurity measures [10].
- Common Approaches to Protection Against Cyber Threats: The technical requirements of ISO/IEC 27001:2022 strengthen the defense mechanisms of AI systems, while ISO/IEC 42001:2023 ensures these defenses are applied fairly and ethically. Thus, a more holistic protection against cyber attacks is provided.

Strategic Advantages and Global Alignment

- Competitive Advantage: Organizations certified with ISO/IEC 27001:2022 and ISO/IEC 42001:2023 gain a competitive advantage in the global market by meeting high standards in both information security and AI management.
- Investor and Customer Trust: The integration of these two standards demonstrates that companies perform strongly in both cybersecurity and ethical AI practices, thereby fostering trust among investors and customers.
- Legal and Regulatory Compliance: An integrated management system enables organizations to adapt more rapidly to international regulations and reduces legal risks.

5. Conclusion and Recommendations

ISO/IEC 42001:2023, thanks to the provisions in its Annex A, enables companies to use AI technologies in a more reliable, transparent, impartial, unbiased, neutral, ethical and sustainable manner. However, the technical, financial and organizational challenges encountered during its implementation necessitate strategic interventions for the effective realization of this standard. Organizations that adopt these standards maintain legal compliance and their reputation while gaining a competitive advantage. When integrated with ISO/IEC 27001:2022, synergies emerge in critical areas such as data security, process efficiency and regulatory compliance. In the future, broader adoption of this integration will accelerate companies' digital transformation processes, enhance their competitive advantage and support long-term sustainability strategies. Comprehensive training programs, advanced technology investments and the development of integrated management systems will ensure maximum utilization of the benefits offered by both ISO/IEC 42001:2023 and ISO/IEC 27001:2022. Accordingly, supporting academic and applied research as well as continuously monitoring new technological developments are of great importance.

ISO/IEC 42001:2023 promotes critical principles such as transparency, accountability, impartiality, neutrality, reliability and ethical compliance in the management of AI applications. Thus, within a comprehensive framework, it prevents many organizations from managing AI systems in a random or unstructured manner and guides them within a certain methodology. Considering the challenges in adopting and effectively implementing this standard;

- Since the standard is still at an early stage, clear implementation guidelines and sector-specific roadmaps are lacking for organizations.
- High implementation costs pose a barrier for small and medium-sized enterprises with insufficient technical infrastructure, as well as organizations in developing countries.
- Lack of coordination among different departments within the organization (HR, Legal, IT, etc.) makes it difficult to implement AI management systems with a holistic approach.
- More technical guidance is needed on how the integration processes with other management systems such as ISO/IEC 27001:2022 and ISO/IEC 9001:2015 should be conducted.

Nevertheless, the necessity of such a standard for the responsible management of AI in organizations is an indisputable fact. While AI systems bring profound changes across many sectors, the widespread adoption of standards like ISO/IEC 42001:2023 will provide a significant advantage in minimizing ethical risks and security threats. Below are some recommendations at the technical and operational levels to implement the ISO/IEC 42001:2023 standard more effectively.

1. Technical Infrastructure and Algorithm Model Security

- AI model risk management processes should be developed. It must be ensured that the datasets used in model training are unbiased, balanced, and comply with ethical standards.
- Protection mechanisms against adversarial AI attacks should be developed. Security measures must be taken against attacks such as model manipulation, data corruption, and reverse engineering.
- Model versioning and continuous validation processes should be clearly defined according to the ISO/IEC 42001:2023 standard. In particular, AI models should be regularly updated and their performance tested.
- Explainable AI (XAI) principles should be further encouraged in AI systems. This enables companies and users to better understand AI decisions.

2. Data Management and Integration with ISO/IEC 27001:2022

- Integration of ISO/IEC 27001:2022 with ISO/IEC 42001:2023 should strengthen the information security processes of AI applications used within the company.
- Data classification and access controls should be detailed specifically for AI models. Access authorizations must be strictly regulated, especially in systems handling sensitive data.
- Data anonymization, encryption and strict access policies should be implemented to maximize data security in AI systems.

3. AI Model Performance Evaluation and Continuous Monitoring

- Within the scope of ISO/IEC 42001:2023, auditing AI models must be made mandatory. Performance monitoring systems should continuously track error rates, inaccuracies and model updates.
- AI model audits should be conducted by independent organizations. Similar to independent audits in information security processes under ISO/IEC 27001:2022, external audit mechanisms should be established for ISO/IEC 42001:2023 as well.
- Automated error detection and correction systems should be developed. When an AI model makes incorrect decisions in a live environment, automatic feedback mechanisms should enable the model to improve itself.

4. Organizational Structure and Human Resource Strategy

- International training programs should be established to cultivate certified experts in ISO/IEC 42001:2023. Companies should implement policies that encourage participation in such programs to ensure they have competent personnel in AI management systems.
- Internal AI ethics committees should be formed within organizations. An internal audit mechanism involving experts from different departments should be created to ensure compliance with ISO/IEC 42001:2023 standards.
- Employee awareness training should be made mandatory. ISO/IEC 42001:2023 should be made comprehensible not only to technical teams but also to all employees within the organization and integrated into corporate training programs.

In line with these recommendations, the ISO/IEC 42001:2023 standard can become more widely applicable within organizations. To ensure the ethical and trustworthy management of AI systems, global

standards such as this must be continuously improved and expanded. ISO/IEC 42001:2023 is one of the most critical steps toward making AI a more reliable, auditable, transparent, unbiased, impartial and sustainable technology in the future. Therefore, its effective implementation requires substantial efforts on both technical and organizational levels.

The key approach for effective implementation of this standard lies in acquiring and thoroughly understanding the technical aspects of AI algorithms and applications. For organizations to successfully implement AI systems, it is not enough to merely use AI tools—they must also understand how these technologies function and how they can be managed. This helps prevent misapplications and ethical violations stemming from a lack of technical knowledge. Many organizations lack sufficient understanding of how AI systems are developed, which algorithms are suitable under specific conditions and what potential risks these algorithms may pose. Thus, fostering close collaboration between companies and academic/technical experts is one of the most critical elements in enhancing the effectiveness of AI management systems.

In terms of the importance of understanding AI algorithms on a technical level, the ISO/IEC 42001:2023 framework encompasses multi-layered technical processes, including data management, model training, algorithm optimization, performance monitoring and model security. The success of AI applications largely depends on the accuracy, reliability and explainability of the underlying techniques—such as machine learning (ML), deep learning (DL), heuristic-metaheuristic algorithms and statistical modeling. An organization that does not understand its own AI systems or how specific algorithms function in different contexts cannot properly implement the management systems required by ISO/IEC 42001:2023. A lack of technical knowledge may lead to the following problems:

- Incorrect algorithm selection: For example, natural language processing (NLP) models used in customer service will not have the same impact as logistic regression or decision trees used in financial risk analysis.
- Data bias and ethical issues: If the datasets used during model training are biased, the model may produce unfair outcomes. Such errors make it difficult for organizations to comply with the ethical requirements of the ISO/IEC 42001:2023 standard.
- Lack of transparency: So-called "black box" AI models may lead organizations to violate core principles of the ISO/IEC 42001:2023 standard, such as accountability, transparency, impartiality and freedom from bias.

It is critically important not only for companies to utilize AI systems, but also to be able to technically analyze how these systems work, manage security risks and continuously improve them.

According to the ISO/IEC 42001:2023 standard, successful implementation of an AI management system requires ongoing interaction among academic experts, technical specialists and industry professionals. While organizations typically focus on business-oriented AI solutions, academic research provides crucial insights for long-term and sustainable development. If organizations fail to collaborate with academic and technical experts in AI management, they may encounter the following issues:

- Rapid but inefficient implementations: When AI technologies are quickly integrated into business processes without sufficient research, they may result in long-term technical weaknesses.
- Low security and high risk: Without in-house experts on AI security, issues such as adversarial attacks, data manipulation and ethical concerns may spiral out of control.
- Legal risks: ISO/IEC 42001:2023 mandates compliance with regulations and ethical principles for AI management systems. Failure to collaborate with academic experts in legal and ethical domains may expose companies to significant penalties due to non-compliance.

For these reasons, it is essential for organizations to work in collaboration with academic experts in order to establish a conscious AI management model based on technical knowledge. Within the framework of the ISO/IEC 42001:2023 standard, the following strategies can be implemented to strengthen the relationship between organizations and academic as well as technical experts:

- Internal AI consulting mechanisms should be established within the organization, with regular meetings held with academics and technical experts. The sustainability of AI projects should be evaluated. Independent assessments and recommendations should be obtained from external experts to develop processes compliant with the ISO/IEC 42001:2023 standard.
- Support for joint research and development (R&D) projects should be provided to foster collaboration between universities and the private sector in AI management and within the framework of the ISO/IEC 42001:2023 standard. Companies should work with academic institutions to participate in studies on ethical evaluation of AI models, algorithm optimization and

security analyses.

- AI training programs and certifications should be developed and organizations seeking compliance with the ISO/IEC 42001:2023 standard should offer technical AI training and ethical awareness programs to their employees. Certification programs should be organized in cooperation with academic institutions to enhance AI competencies within the organization.
- Joint data-sharing protocols between organizations and universities should be established to enable academic experts to actively participate with organizations in dataset creation, model training and performance evaluation processes. A data governance mechanism compliant with ISO/IEC 27001:2022 should be created to ensure secure data sharing.
- AI model audit and testing processes should be conducted with academic support. Academic experts should provide consultancy to organizations to evaluate AI model performance, analyze error rates and identify potential security vulnerabilities. Real-world simulations should be used in AI model testing processes to ensure the model's ethical compliance and data integrity.

For the successful implementation of the ISO/IEC 42001:2023 AI management system standard, technical analyses of AI systems should be made more comprehensive within the framework of industry-academia collaboration, and information sharing within organizations should be enhanced.

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Advances in Artificial Intelligence Research (AAIR)
ISSN 2757-7422
www.dergipark.com/aair/

Vol. 5 (No. 2), pp. 23-31, 2025
doi: 10.54569/aair.1677931PID
Published online: June 16, 2025

Determination of Oxygen Requirement of Trout

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Abstract

Today, e-commerce sites provide a large number of products to users. However, presenting the right products to users is important for both customer satisfaction and increasing company revenues. Recommendation systems are systems that offer personalized product suggestions by analyzing user preferences and behaviors. This study presents a novel hybrid product recommendation system that integrates collaborative filtering and content-based filtering methods, enhanced by deep learning techniques. By using both visual and textual product features through BERT and CLIP models, our system addresses cold-start problem and real-time performance constraints. The system has been successfully deployed on the Cimri e-commerce platform, providing personalized recommendations that adapt to evolving user preferences while maintaining computational efficiency.

Keywords: *Trout, Oxygen level, Oxygen requirement, Dissolved Oxygen*

1. Introduction

Today, aquaculture has become a significant part of modern life. Activities related to fish farming in environments such as rivers, seas, lakes, and dams have been increasingly gaining importance [1].

Water is not inherently rich in oxygen content. While one liter of air contains approximately 300 mg of oxygen, one liter of water at 15°C contains only 10 mg of oxygen. The capacity of water to retain oxygen also depends on its temperature. In warm water, the ability to retain oxygen is lower, whereas it is higher in cold water. Therefore, in aquaculture, the oxygen required for fish is provided either by introducing a very high volume of water into the farm or by injecting pure oxygen into the water. To establish a trout farm, the minimum flow rate of the water source must be between 20–25 liters per second. The more this value exceeds the minimum requirement, the more stable the system becomes. The reason for such a high demand for water is the substantial oxygen requirements of trout [2].

In a study conducted by Dandy (1970), the activity levels of trout were measured at 10°C under three different oxygen concentrations. It was reported that the oxygen-related activity of fish exposed to dissolved oxygen levels ranging from 1.7 to 6 ppm peaked within the first hour [3].

In their study, Doudoroff and Shumway (1970), reported that the dissolved oxygen concentration in waters inhabited by trout should be 11 mg/L during the initial stages of life, while for other life stages, a level of 8 mg/L was considered sufficient. They also stated that the minimum dissolved oxygen concentration required for warm-water fish is 5 mg/L, whereas for cold-water species, including trout, it should not be less than 6 mg/L [4].

Downey and Klontz (1981), identified the minimum and average oxygen requirements for trout at specific water temperatures. In their research, they indicated that at a water temperature of 20°C, the minimum necessary dissolved oxygen level was 7.8 mg/L, while the average requirement was 5.90 mg/L. They also mentioned formulas that assist in calculating the oxygen consumed per fish and in managing oxygen consumption [5].

Drewett and Abel (1983), conducted a study comparing two distinct trout diseases. Their findings revealed that fish exposed to low levels of dissolved oxygen experienced tissue damage, which could only be observed under an electron microscope [6].

Weithman and Haas (1984), noted in their study that in water sources where aquaculture is widely practiced, the onset of autumn leads to oxygen depletion, making aquaculture conditions increasingly challenging. They reported that the dissolved oxygen levels in such environments ranged between 2.4 and 6.0 mg/L [7].

Raleigh et al. (1984), indicated that the optimal dissolved oxygen concentrations for rainbow trout are >7 mg/L at temperatures below 15°C, and >9 mg/L when temperatures exceed 15°C. They emphasized that the oxygen requirements of trout species are higher compared to other fish, and that available comparative data suggest remarkably similar dissolved oxygen needs across all trout species [8].

Chapman (1986), proposed a minimum dissolved oxygen level of 4.0 mg/L to prevent mortality, and a chronic threshold of 6.5 mg/L to safeguard natural populations from impaired reproduction [9].

Dean and Richardson (1999), conducted a study in which they kept seven species of freshwater fish in low dissolved oxygen conditions to determine their tolerance levels to dissolved oxygen. The study was conducted

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Received: April 16, 2025; Accepted: June 14, 2025.

over a period of 48 hours at dissolved oxygen levels of 1.3 or 5 mg/L. The results showed that the fish survived at a concentration of 5 mg/L with a survival rate of 90-100%. All species were exposed to a 3 mg/L concentration for 36 hours, and it was reported that an average of 14.3% of rainbow trout died. As a result, they concluded that trout are the most sensitive species to dissolved oxygen compared to other fish [10].

Yanık et al. (2001), found in their study that the desired level of dissolved oxygen should exceed 5 mg/L, with fish surviving in the range of 1.0–5.0 mg/L but experiencing slow growth. They reported that dissolved oxygen levels in the range of 0.3–1.0 mg/L were lethal over prolonged exposure, and that in the range of 0–0.3 mg/L, small fish could survive for only a brief period [11].

Bayrak (2006), planned the oxygen content to be in the range of 9.2–11.5 mg/L for saturation, but during periods of high-water temperature, he observed that the oxygen content of the water decreased, with levels at the pond inlet ranging from 4.8 to 6.5 mg/L [12].

Güleçal (2007), conducted a study aimed at determining the efficiency level during the first 60 days of raising juvenile fish. He reported that in rainbow trout farming, the oxygen content of the water should not be less than 6 mg/L. He indicated that a lack of oxygen affects development and metabolism, and that the oxygen level of the water should be between 9–11 mg/L until the trout juveniles reach a weight of 8 grams [13].

Swales (2009), demonstrated in his study that rainbow trout prefers water temperatures below 22°C. He reported that rainbow trout are rarely found in waters where oxygen levels are significantly below 3.0 mg/L and tend to avoid dissolved oxygen concentrations below 2.5 mg/L, which can define the lower depth limit of trout distribution in lakes [14].

Frankin (2013), conducted a study on various trout species, including species native to New Zealand, by keeping them at 15°C for 48 hours in water with fixed dissolved oxygen concentrations of 1, 3, and 5 mg/L to examine their tolerance to low dissolved oxygen levels. He found that the Common Kabaday (Gobiomorphus cotidianus) and juvenile Rainbow Trout (Oncorhynchus mykiss) were the most sensitive species to low dissolved oxygen levels [15].

Sırtkaya (2013), stated in his study that the oxygen content of the water should be at least 5–6 mg/L and that the minimum oxygen requirement for maximum growth is 6 mg/L [16].

2. Material and Method

Trout are aggressive, carnivorous fish that prefer cold, clear, and fast-flowing waters. Trout, belonging to the Salmonidae family, favor environments that are clear, clean, cool, and oxygen-rich. The most used species in trout farming is the Rainbow Trout, which originates from North America [17]. Rainbow trout shows superior adaptation to farming conditions compared to other trout species, its higher tolerance to low oxygen levels and temperature, its lower need for shelter, and its greater resistance to stress, in addition to its excellent meat quality, have made this species quite popular [16]. Spring waters are suitable for the farming of many cold-water fish, including trout. Stream springs (Rheokren) are clean, clear, cold, and have minimal temperature fluctuations, but they are oxygen-poor. These springs are quite suitable for trout farming, and to enrich their oxygen content, external sources of oxygen should be introduced to the system. Lake-type springs (Limokren) are oxygen-poor sources with stable water temperatures. They are particularly suitable for fattening and juvenile trout farming, especially during incubation. Swamp-type springs (Halokren) are influenced rapidly by seasonal temperature changes. Their oxygen content is very low, and the water contains high organic matter, particularly humic acid, making the water acidic and unsuitable for trout farming. Rivers are oxygen-rich, making them suitable for trout farming. Water temperatures vary significantly depending on altitude, the region where the spring is located, meteorological conditions, and the seasons [17].

Fluctuations in water temperature are known to cause stress, which is primarily due to low oxygen concentrations at higher temperatures. If excessive oxygen is supplied, it may make the fish more susceptible to diseases [18]. At the start of spring, the water temperature in ponds is uniform from the surface to the bottom, showing little variation. However, as the weather warms up, surface waters heat up, causing a decrease in their density. In early summer, stratification occurs in the ponds, creating three primary layers: the upper layer, known as the epilimnion, which is rich in oxygen and relatively warm; the transition layer, known as the metalimnion, where sudden temperature drops occur; and the bottom layer, the hypolimnion, which is oxygen-poor and cold. These layers are shown in **Fig. 1** [11].

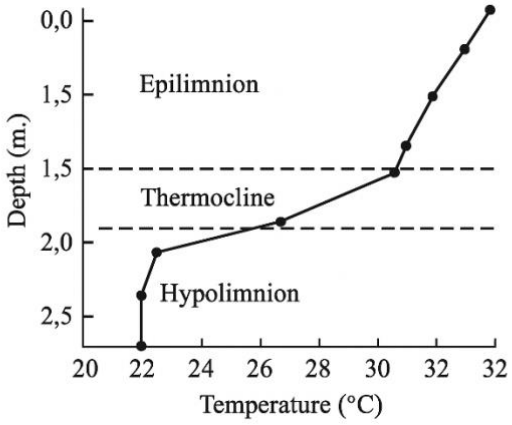

Figure 1. *Stratification occurring in summer*

2.1. Oxygen Requirement of Trout

The oxygen requirements of fish are generally expressed in terms of "ppm." This quantity refers to milligrams per liter (mg/L) depending on the oxygen pressure (1 ppm = 1 mg/L). For example, the retention of 2 mg/L of oxygen occurs at an oxygen pressure of 42 mm at 30°C and 33 mm at 15°C. The formula used to approximately estimate oxygen consumption is shown in Eq. 1 [11].

$$Y = \frac{0.001}{W * 0.82} \tag{1}$$

In this equation, Y represents oxygen consumption (g/hour), while W refers to weight in grams. In aquaculture, oxygen deficiency occurs when more oxygen is not added to the water than is consumed by organisms or if it cannot be replenished by plankton. Oxygen loss in water occurs through the respiration of plankton, fish, benthic organisms (organisms living in the mud), and diffusion (the movement of substances between areas of different densities). In the absence of an oxygen kit or an oxygen meter, oxygen deficiency can be estimated. Factors such as fish swimming near the water surface during late night or early morning hours, sticking their heads out of the water to gulp air, a sudden cessation of feeding, changes in water color, or the emission of a rotten odor from the water can make it easier to predict oxygen deficiency [11].

In a closed system, to maintain oxygen balance, the number and size of the fish must be proportional to the water volume and surface area of the closed system. Fish can survive on the dissolved oxygen in the water; however, in closed systems with a small water surface area, fish can run out of oxygen. In such cases, fish gather at the surface of the water to obtain oxygen. These issues can be addressed through aeration methods. Another method involves air injectors, which use a motor to draw water from one tank and push it into another, enriching the water with oxygen as it circulates between the tanks. Oxygen diffusers are used to increase oxygen levels in the water when necessary. They are used in fish farming ponds, live fish transport tanks, live feed production, hatcheries, adaptation ponds, and large aquariums [19].

2.2. Dissolved Oxygen

Dissolved oxygen refers to the oxygen molecules dissolved in water. Oxygen does not dissolve easily in water. Under normal conditions, oxygen can only dissolve at 12 mg per liter. Oxygen enters water from only two sources: either it dissolves by coming into contact with the atmosphere, or it is produced by plants during photosynthesis. The removal of trees and plants along the banks of rivers and streams reduces shading, leading to higher water temperatures. This indirectly causes lower dissolved oxygen concentrations because warmer water holds less oxygen. Dissolved oxygen should be measured immediately after sampling. Changes in temperature and the continued consumption of oxygen by bacteria in the water can affect the measurements. Dissolved oxygen is typically measured with a field probe or collected in a special bottle, then chemically fixed before being transported to a laboratory for analysis [23]. In aquatic environments, the oxygen content is controlled by the activities of phytoplankton and bacteria. A huge portion of the oxygen is produced by phytoplankton during photosynthesis. Excessive algal growth obstructs sunlight from penetrating the water surface, preventing photosynthesis. As a result, dead algae sink to the bottom, depleting dissolved oxygen in the benthic environment [20].

Dandy (1970), measured the locomotor activity (musculoskeletal system) of rainbow trout at three different oxygen concentrations at 10°C. He found that the oxygen-related activities of the trout peaked within the first hour at dissolved oxygen levels ranging from 1.7 to 6 mg/L and gradually decreased thereafter. Trout exposed

to 1.7 mg/L of dissolved oxygen had an average survival time of 130 minutes, and their responses were more related to the absolute concentration of oxygen than its rate of decline [3].

Doudoroff and Shumway (1970), summarized studies on lethal dissolved oxygen concentrations for many species, including rainbow trout, which are generally considered the most sensitive group of freshwater fish. In their study, they reported that for rainbow trout, dissolved oxygen levels were 11 mg/L during the early stages of life and 8 mg/L during later stages. They indicated that a water source with an oxygen saturation level above 80% is considered healthy, and that the minimum dissolved oxygen concentration for warm-water fish should be at least 5 mg/L, while for cold-water fish, it should be at least 6 mg/L [4].

In their study, Downey and Klontz (1981), showed the minimum and average dissolved oxygen requirements for rainbow trout at various water temperatures. **Table 1** presents the minimum required dissolved oxygen, while **Table 2** shows the average required dissolved oxygen concentrations [5].

Table 1. *Temperature-dependent minimum dissolved oxygen requirements for trout*

Temperature (°C)	D.O. (mg/L)	% Saturation	Partial Pressure of Oxygen (mmHg)
5	9,1	71,26	113
10	8,8	78,01	123
15	8,3	82,4	129
20	7,8	85,9	133,7

Table 2. *Temperature-dependent average dissolved oxygen levels required for trout*

Temperature (°C)	D.O. (mg/L)	% Saturation	Partial Pressure of Oxygen (mmHg)
0	8,34	57	90
5	7,28	57	90
10	6,43	57	90
15	5,94	59	92
20	5,90	65	101

Drewett and Abel (1983), conducted a study comparing two different trout disorders. In this study, they reported that fish remaining at low dissolved oxygen levels suffered tissue damage, which could only be observed under an electron microscope. They noted that brown trout survived for an average of 50 minutes at 1 mg/L and 90 minutes at 1.5 mg/L [6].

Weithman and Haas (1984), established a trout farming facility in Lake Taneycomo. Through detailed examination from June 1978 to May 1980, they indicated that the success of fishing declined during the autumn as oxygen-poor waters entered the lake. They reported that the catch rate of rainbow trout during the study was 0.55 fish per hour. They also noted that the dissolved oxygen concentration ranged from 2.4 to 6.0 mg/L, and when reduced by 1 mg/L, the catch rate dropped by 0.1 fish per hour. They concluded that low dissolved oxygen concentrations would result in economic losses during production [7].

Raleigh et al. (1984), stated that for rainbow trout, dissolved oxygen levels should be at least 7 mg/L in waters with temperatures below 15°C, and at least 9 mg/L in waters above 15°C. They highlighted that trout species require higher oxygen levels than other fish species, and the comparative data available indicates that all trout species share quite similar dissolved oxygen requirements [8].

Chapman (1986), suggested that a dissolved oxygen concentration of 4.0 mg/L should be considered the lower threshold to prevent mortality in trout, and a chronic threshold of 6.5 mg/L should be maintained to protect natural trout populations from production disorders [9].

Dean and Richardson (1999), conducted a study on seven freshwater fish species, including some native to New Zealand, to determine their tolerance to low dissolved oxygen levels. The fish were kept at dissolved oxygen levels of 1.3 or 5 mg/L for 48 hours. The species used in the study included: Inanga (Galaxias maculatus), Banded Kokopu (G. fasciatus), Whitebait (Retropinna), Torrent fish (Cheimarrichthysforti), Common Galaxiid (Gobiomorphus cotidianus), Shortfinned and Longfinned Eels (Anguilla australis and A. dieffenbachii), and shrimp (Paratya curvirostris). Rainbow trout (Oncorhynchus mykiss) was tested for comparison. The results showed that the fish survived at 5 mg/L concentration with a survival rate of 90-100%. All species were exposed to a 3 mg/L concentration for 36 hours, and it was reported that an average of 14.3% of the rainbow trout died. At a 1 mg/L concentration, the mortality rates varied significantly, with Banded Kokopu, Torrent Fish, Whitebait, Galaxiid juveniles, and all trout species dying after 48 hours. The study concluded that rainbow trout were the most sensitive species to dissolved oxygen compared to others. **Table 3** shows the required dissolved oxygen levels based on the degree of acceptable deterioration in waters where trout is present or absent [10].

Table 3. *Acceptable dissolved oxygen concentrations relative to degradation levels in trout-inhabited and trout-absent waters (mg/L)*

Acceptable Level of Degradation	Waters Inhabited by Trout		Waters Not Inhabited by Trout	
	Early Phase	Following Periods	Early Phase	Following Periods
None	11	8	6,5	6,0
Slight	9	6	5,5	5,0
Moderate	8	5	5,0	4,0
Severe	7	4	4,5	3,5
Critical Threshold	6	3	4,0	3,0

Yanık et al. (2001), addressed the relationship between oxygen solubility in water and salinity in their study. They stated that for every 9000 mg/L increase in salinity, the solubility in pure water decreases by 5%, and therefore, the effect of salinity is not considered significant in freshwater environments. They reported that cold-water species die in situations where dissolved oxygen levels are higher than those found in warm-water species. They mentioned that rainbow trout can survive for a minimum of 84 hours in a range of 1.05-1.34 mg/L dissolved oxygen. **Table 4** shows the oxygen solubility in pure water at different temperatures, and Figure 2 illustrates the dissolved oxygen levels that pond fish can tolerate [11].

Table 4. *Oxygen solubility in pure water at different temperatures*

Temperature (°C)	D.O. (mg/L)	Temperature (°C)	D.O. (mg/L)	Temperature (°C)	D.O. (mg/L)
0	14,16	12	10,43	24	8,25
1	13,77	13	10,20	25	8,11
2	13,40	14	9,98	26	7,99
3	13,05	15	9,76	27	7,86
4	12,70	16	9,56	28	7,75
5	12,37	17	9,37	29	7,64
6	12,06	18	9,18	30	7,53
7	11,76	19	9,01	31	7,42
8	11,47	20	8,84	32	7,32
9	11,19	21	8,68	33	7,22
10	10,92	22	8,53	34	7,13
11	10,67	23	8,38	35	7,04

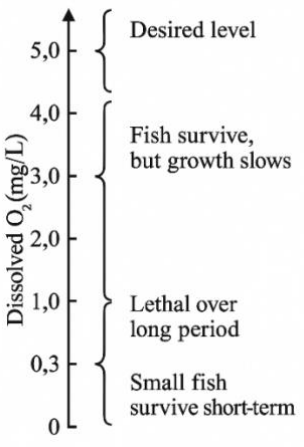

Figure 2. *The amount of dissolved oxygen that pond fish can tolerate*

Bayrak (2006), conducted a study on the reproductive performance of rainbow trout and the survival rates of larvae during the off-season egg production at a commercial trout farm during the 2004 season. The planned oxygen levels were set at 9.2-11.5 mg/L saturation, but during periods of high-water temperature, the oxygen content in the water decreased, and the values at the pond inlet were reported to be 4.8-6.5 mg/L [12].

Güleçal (2007), carried out a study aimed at determining the efficiency level during the first 60 days of trout farming. He reported that the oxygen content in water should not fall below 6 mg/L for rainbow trout farming. Oxygen deficiency affects growth and metabolism, and he emphasized that the oxygen level in water

should be between 9-11 mg/L until the trout larvae reach 8 grams in weight. He also stated that the required dissolved oxygen during the growth period of trout is higher compared to other developmental stages [13].

Swales (2009), in his study indicated that rainbow trout prefer water temperatures below 22°C and are rarely found in waters where oxygen levels are below 3.0 mg/L. He stated that the upper temperature threshold for rainbow trout habitat in lakes and reservoirs is typically around 21°C, with the lower threshold for dissolved oxygen being generally around 2.5 mg/L. However, he noted that rainbow trout can tolerate conditions outside these limits for short periods, such as in shallower waters during the summer [14].

Frankin (2013), studied different trout species, including those native to New Zealand, by keeping them at fixed dissolved oxygen levels of 1, 3, and 5 mg/L for 48 hours at 15°C. The study concluded that rainbow trout is the most sensitive species to low dissolved oxygen levels among those tested. He reported that when dissolved oxygen levels fell below the tolerable limits, it contributed to changes in the community structure [15].

Sırtkaya (2013), in his study found that the water's pH should be between 6.5 and 8.5, with the optimum being around 7. He indicated that pH levels below 5.0 or above 9.2 are lethal for trout. He also noted that the oxygen content in the water should be at least 5-6 mg/L, with the minimum oxygen requirement for maximum growth being 6 mg/L. Growth stops when the oxygen level is 3 mg/L, and at oxygen levels of 0.75-1.3 mg/L, the fish die. He further stated that the necessary minimum oxygen values during farming should be >5.0 mg/L for salmonids and around 7 mg/L for salmonid eggs [16].

2.3. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

Biochemical Oxygen Demand (BOD) only measures the oxygen consumed by organic matter that is broken down through biochemical processes, while Chemical Oxygen Demand (COD) measures not only the organic pollutants that are broken down biochemically but also toxic organic pollutants. Additionally, while determining the BOD requires at least five days, the COD can be determined in as little as three hours. Chemical oxidizers such as potassium dichromate or potassium permanganate give values close to the BOD for many organic pollutants. **Table 5** shows the classification of rivers based on BOD values [21].

Table 5. *Classification of water sources based on approximate biochemical oxygen demand (BOD) values*

Approximately BOD (20°C, ppm)	Definition of water
1	Excellent
2	Clean
3	Moderately Clean
5	Doubtful
10	Poor

2.4. Formulas Used to Determine Oxygen Needs of Trout

Dissolved oxygen concentrations are highest at 0°C and decrease with increasing temperature. The formula used to correct the solubility of oxygen for different atmospheric pressures is shown in Eq. 2 [11].

$$DOc = DOt * (((P0 - Pw)) / (760 - Pw)) \quad (2)$$

In this formula, DOt represents the oxygen solubility at 760 mm pressure, DOc represents the corrected oxygen solubility, P0 represents the specified atmospheric pressure, and Pw represents the vapor pressure of water. The oxygen retention in water depends on temperature. The calculation of the oxygen concentration in fully aerated water is shown in Eq. 3 [12].

$$\mathrm{Cs} = 468 / (31{,}6 + \mathrm{t\,°C})\ \mathrm{mg\ oxygen/liter} \quad (3)$$

Here, T represents the water temperature. Cs shows the oxygen content in water at 100% saturation and is used only for concentration measurement in fresh waters. The formula used to calculate the maximum dissolved oxygen amount at a specific temperature is shown in Eq. 4 [22].

$$Pc\ (max) = 2.07 + 3.06\ InT \quad (4)$$

For example, at 5 °C, the maximum dissolved oxygen amount is calculated as 7.0 mg O2/L. As salinity increases, the oxygen content in water decreases exponentially. The formula used to calculate the salinity rate is shown in Eq. 5 [22].

$$Salinity = 1{,}80655 * Chlorinity \quad (5)$$

The main parameters controlling the dissolved oxygen concentrations in rivers are widely described in scientific literature. The formula used to calculate dissolved oxygen concentration is shown in Eq. 6 [15].

$$\frac{dC}{dt} = k2(Cs - C) + (P - R) - k3x \quad (6)$$

Here, C represents the dissolved oxygen concentration, Cs represents the temperature-dependent saturation value of dissolved oxygen, k2 is the re-aeration coefficient, P is the photosynthesis rate of plants at time t, R is the respiration rate of plants at time t, and k3 is the biochemical oxygen demand (BOD) degradation coefficient.

The calculation of the oxygen consumed per fish in a fish farming facility is shown in Equation 7, and the calculation of oxygen consumption management is shown in Eq. 8 [5].

$$\frac{fish}{gpm} = \frac{(Oin - Oout)}{Yn} \quad (7)$$

Here, Oin represents the dissolved oxygen concentration in incoming water in ppm, Oout represents the dissolved oxygen concentration in water leaving the pond in ppm, and Yn represents the oxygen requirement for a fish of size "N."

$$\frac{fish}{pond} = \frac{1{,}2 * (Oin - Oout) * Rw}{K * T^N * W^M} \quad (8)$$

Also, Oin represents the dissolved oxygen in incoming water in ppm, Oout represents the dissolved oxygen in water leaving the pond in ppm, the constant 1.2, Rw is the water inflow in gpm, K is the ratio constant, T is the water temperature in Fahrenheit, N is the Temperature-Water Slope, W is the individual fish weight in pounds, and M is the weight-oxygen slope.

3. Conclusion

As a result of the research, the necessary parameters for determining the oxygen requirements of trout have been examined. When looking at the natural habitats of the fish, the most suitable sources are flowing sources such as rivers, and pond-type sources. It can be said that the oxygen obtained externally in areas where the oxygen amount is insufficient does not pose any problems in terms of production. It can be stated that a facility to be opened as an operation is more cost-effective when it is close to the source, and in facilities with elevation differences, the water should be brought to the pond in a cascading manner, if possible. Although the lower oxygen content in water compared to air is a problem, the water temperature and external oxygen supply methods seem to be the solution to this issue.

The dissolved oxygen amounts as the oxygen requirement for fish have been comprehensively studied in the conducted research, and it can be said that the values differ from author to author. The oxygen requirements for trout according to different authors are summarized in **Table 6**.

Table 6. *Minimum dissolved oxygen requirements for trout according to various authors (mg/L)*

Downey and Klontz (1981)	**7,8 at 20°C**
Raleigh et al. (1984)	7 at 15° and above 9 at 15°
Chapman 1986	6,5
Kramer 1988	2,4-6,0
Dean and Richardson 1999	8
Yanık et al. 2001	5
Bayrak 2006	9,2-11,5
Güleçal 2007	6
Swales 2009	2,5 at 21°C
Bulut 2012	6
Franklin 2013	5 at 15°
Sırtkaya 2013	5-6
Bulbul et al. 2022	5-6

4. Discussion and Future Work

In the conducted research, a comparison has been made regarding the dissolved oxygen requirements of trout according to different authors. Although there is no universal value, based on the studies reviewed, the minimum oxygen requirement for trout has been indicated as approximately 5 mg/L. This value can be considered as the minimum level required in the maturity phase, following the growth stage of trout. The dissolved oxygen values mentioned in the studies can be summarized as a general value of 5-8 mg/L for trout species. The different opinions of the authors, as well as the average of the dissolved oxygen values stated by the same authors, have been visualized on a graph and are shown in **Fig. 3**.

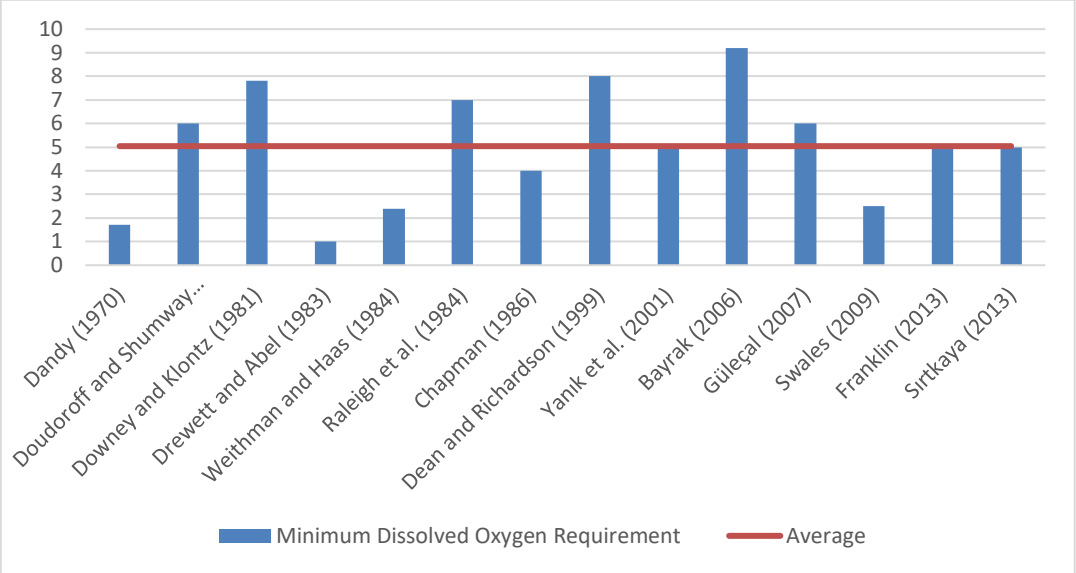

Figure 3. *Minimum and average dissolved oxygen requirements for trout according to various authors (mg/L)*

In future studies, the determination of the oxygen requirements for trout could be further developed by considering parameters such as the differences in water sources, water temperatures, various trout species, and their maturity levels. When evaluating the authors for different parameters, a separate average value can be determined for each parameter. On the other hand, by creating a database based on certain predefined parameters, a prediction method can be implemented using various types of artificial intelligence algorithms. Based on the obtained data, the required amount of dissolved oxygen can be determined with greater accuracy.

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Advances in Artificial Intelligence Research (AAIR)
ISSN 2757-7422
www.dergipark.com/aair/

Vol. 5 (No. 1), pp. 32-41, 2025
doi: 10.54569/aair.1709274
Published online: June 16, 2025

Customer Churn Prediction with Machine Learning Methods In Telecommunication Industry

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Abstract

With the emergence of new competitors and increasing investments in telecommunication services, change often occurs and hence importance of marketing strategies and customer behavior prediction have become an important demand for companies. New regulations and technologies increase competition among mobile operators. Since acquiring a new customer is more expensive than acquiring active customers, companies seek solutions to reduce the churn rate. Therefore, telecommunications companies want to analyze the concept of the customer's desire to change service provider and take necessary measures to protect their existing customers. In this study, usage information, usage trends, subscription commitment, subscription age, ARPU and billing information, competitor familiarity, outgoing call information, number porting experience, etc. Loss estimation modeling is taken into account. Dataset includes 593 columns and 1826588 lines. Corporate mobile customers are analyzed by dividing into three subgroups as Single Line Mobile Customers, 2-5 Line Mobile Customers, and 6-15 Line Mobile Customers. In order to estimate customer loss, four different ML methods are used while creating loss prediction models. The model is developed by using 600 different variables and loss estimation. ROC curves and lift chart results for different corporate mobile customer groups are compared, and the most suitable models are depicted.

Keywords: *Machine Learning; Telecommunication; Churn Prediction; Random Forests; Customers; Data Analysis; AI*

1. Introduction

Customer retention is one of the most important issues for companies in today's competitive business environment, especially in telecom industry. New regulations and technologies allow easy switching between mobile operators. The process of switching from one service provider to another compromises various parameters, such as good services or rates, or the competitor's providing various advantages to customers, arising an essential problem in a highly competitive and rapidly developing industry. Telecommunication sector has a very high customer loss rate [1-3]. In today's conditions, since acquiring a new customer is more expensive than keeping an existing customer, companies take every precaution to retain their customers. Therefore, identifying factors that cause customers to move away due to different reasons, such as withdrawal, running away... should be handled with priority in terms of competitiveness and sustainability.

Churn refers to the number of customers that the business has lost in a period. Churn Analysis, determining the situations that cause customer loss and estimating churn rate, has become crucial. According to research [3-7], acquiring a new customer costs 5 times more than retaining existing customers. In addition, it costs 10 times more to acquire an unsatisfied customer than to retain existing customers. Although operators in France making large customer acquisition expenditures [8], they lose about 30 percent or more of their subscribers annually. For this reason, companies develop new strategies by looking for different solutions to retain their existing customers. In [6, 9], customer churn management is defined as to predict customers that are about to lose by looking at customers' behavior and to find the right marketing strategy to retain these customers. [10] shows that even small increases in retention are important to a company's profitability. [11] argues that even a 1 percent increase in customer retention has a significant impact on results. Therefore, companies are conducting various studies to improve customer churn estimation.

Big data analytics and machine learning techniques are used to predict customer churns. With the increasing importance of marketing strategies and the conscious behavior of customers, the Customer Relationship Management (CRM) approach has become a priority for companies. As part of this, loss forecasting models are applied to identify potential customer losses. The most effective method of customer retention is accurate loss forecasting models and effective loss prevention strategies. The main purpose of this project is to find the best model in the scope of CRM with machine learning models to predict customer churn in the telecommunications industry. SAS Miner and SAS EG programs are used for statistical analysis. While applying loss estimation models, data mining and machine learning methods are used.

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Received: May 30, 2025; Accepted: June 14, 2025.

The increase in customer churn rate from 20 percent to 40 percent is worrying for telecommunications companies. In the article, various methods are proposed to estimate customer losses, the results are compared and evaluated with statistical analysis. In this project, customer usage information, usage trends, subscription commitment, subscription age, contact/invoice information, competitor acquaintance, outbound call information, number porting experience, silent lines were taken as the main criteria. The main contribution of our work is to develop a churn prediction model which assists telecom operators to predict customers who are most likely subject to churn. The dataset contained all customers' information over 12 months, and is used to train, test, and evaluate the system at a big Telecommunication company in Turkiye. The model experimented four algorithms: Decision Tree, Random Forest, Gradient Boosted Machine Tree "GBM" and Extreme Gradient Boosting "XGBOOST" as depicted in **Fig. 1**.

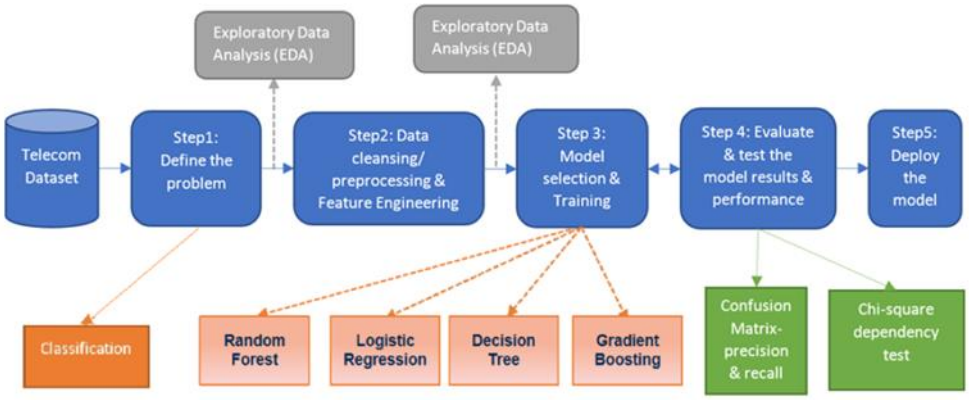

Figure 1. *Learning/Prediction steps for churn prediction process.*

2. Related Work

In the telecommunication domain, there are still various important open problems [3, 6, 7, 12], and among those churn prediction is one of the major and urgent problems. In [1], the researcher applies face-to-face surveys to many customers in order obtain their mobile phone usage perception. [13] analyzes churn detection problem with ML techniques and social media data is combined as a supporting information and they obtain the best results with Gradient Boosting. In other research [14], DCNN is used to predict churn and gives high results. However in their work they deal with only 18.000subscribers, which is relatively small data size in this domain. In [15] researchers combine game players communication in text and extract player comments from games, which is later used to predict tendency in their opinion for churn. In [16] a big amount of data, 127 million, is extracted to analyze user behavior by using various ML techniques and observe their performance. However they focus on three parameters only, that are time, frequency and money spend during a period. In their work [17], they focus on land-line customer churn prediction and evaluates 7 different ML techniques across various parameters. Other group [18] of researchers highlight three data challenges in churn prediction domain: 1) the customer churn data set is substantially imbalanced in reality, 2) the samples in feature space are relatively scattering, 3) the dimension of feature space is high. They use random forest for dimension reduction and apply decision tree for classification. This emphasizes the importance of our work well.

3. Churn Prediction Framework

The decision of the customer to terminate the relationship with the existing telecommunications firm is called churn. If a firm has a 70 percent loyalty rate then the churn rate is 30 percent. When working on the churn prediction, it is important to understand the business field and dataset in detail. In this study, datasets are prepared using SQL queries. Since binary variables are used in this project, the model is applied as Churn / Not Churn. The work done in this project is carried out in the SAS Miner program and integrated into the codes in SAS EG as Proc SQL.

3.1. Dataset and Evaluation

Data pre-processing, cleaning, transformation, and data selection are handled initially. Blank values and missing values are replaced with the mean or median of the column. Converting the continuous variable to a significant factor variable is used to improve model performance and help understand insights of the data. It is also necessary to check the format and adjust the parameters to the appropriate format. By drawing histograms and box plots, outliers in the data set can be understood. In addition to outliers, the data set contains duplicate values, and these duplicate values are removed from the data set for proper analysis.

Some parameters such as accuracy, sensitivity, recall or F1 score can be calculated to test whether the model

works correctly. For evaluation, for example, 30% of the data set aside for testing and 70% is used in the training phase. The results are evaluated by looking at the relationship of the ROC curve with the cumulative gains and lift curve. Lift is a widely preferred evaluation matrix in marketing strategies [14,18, 22]. The Lift Chart measures the effectiveness of models by calculating the ratio between the result obtained with a model and the result obtained without a model. The Cumulative Lift Chart represents the lift factor which shows how many times it is better to use a model in contrast to not using a model. The probability of customer churn based on the customer's contract and operational data (P (Churn = 0/1)) is calculated. Based on this probability, a predicted class data line will be assigned (Churn) = 0/1. Remember that customers with churn = 0 are, hopefully, much more customers with churn = 1 than customers with Churn = 1.

In the ROC curve, the true positive rate (Sensitivity) is plotted in the function of the false positive rate (100-Specificity) for different breakpoints of a parameter. Each point on the ROC curve represents a sensitivity / specificity pair corresponding to a certain decision threshold. The area under the ROC curve (AUC) is a measure of how well a parameter can distinguish two groups. Specificity is true negatives divided by sum of true negatives and false positives. True negatives can be described as predicted customers who will not churn, actually non-churners. However, if model predicts customer will not churn, but in reality, it will churn, this is false positive. The main difference between specificity and sensitivity is specificity measures proportion of actual negative cases, that identified correctly whereas sensitivity measures proportion of actual positive cases, that identified correctly. Precision gives the proportion of shakers actually leaving the company. F1 Score value gives us the harmonic average of Precision and Recall values. The reason why it is a harmonic average instead of a simple average is that extreme cases cannot be ignored. If a simple mean calculation was used, the F1 Score of a model with a Precision value of 1 and a Recall value of 0 would be 0.5. This does not give an accurate result. The main reason for using the Score value instead of Accuracy is not to make an incorrect model selection in non-uniform data sets. In addition, F1 Score is very important in the evaluation of the model, as a measurement metric is needed that includes not only False Negative or False Positive, but also all error costs.

$$F_1\ Score\ =\ \frac{2 \times Pecision \times Recall}{(Pecision + Recall)} \tag{1}$$

Cost sensitive learning was applied by using weighted random forests, one of the machine learning methods. As we predict a stochastic gradient increasing learner, another method used is boosting. Many comparative studies such as logistic regression, decision tree, gradient boosting and random forest were made in the article. In this study, churn estimation of mobile customers of one of the largest telecommunications companies has been made. The data is real and big. Therefore, it differs significantly from the methods used in previous comparative studies. Classification is more difficult as it is studied on big data and real data.

3.2. Implementation Details

The data is taken from marketing intelligence department of a large telecom company, so Corporate Mobile Customer audience is selected and analyzes are carried out on soho and sme audiences. Loss estimation modeling is performed by analyzing the usage information of customers, usage trends, subscription commitment, subscription age, ARPU (average revenue per user) and billing information, competitor familiarity, outgoing call information, number porting experience, etc. Random Forest, Regression Analysis, Decision Tree and Gradient Boosting machine learning methods [19, 20, 21] are applied and the developed prediction methods are currently being used for monthly churn forecasts [22, 23]. SAS Enterprise Miner tool is used in the study and processes a validation dataset as a way of measuring model performance independently. Verification data set is formed by segmentation of raw analysis data. In the SAS Enterprise Miner program, a third part called test data set can also be created. The test data set provides unbiased estimates of model performance from a single selected model. Methods available in the tools [24-26] are Regression, High Performance Regression, Decision Trees, Random Forest, High Performance Tree, Variable Selection, Stat Explore, Variable Selection, LARS/LASSO, High Performance Variable Selection, Variable Clustering, Principal Components and Weight of Evidence. The data set includes 593 Columns and 1826588 lines.

4. Enterprise Mobile Customers Churn Prediction

The data set consists of postpaid mobile SME and SOHO customers as in **Fig. 2** with active voice usage, with a maximum subscription age of more than 2 months, 15 or less lines. (SME: Small and Medium-sized Enterprises, SOHO: Small Office/Home Office) A learning set covering different seasonal periods (over a year) is applied in order to reduce the seasonal effects on customer basis and to eliminate the incidental effects that may be seen in a certain period. In order to measure the consistency and reliability of the model, a test is conducted over 2 months proving the generalizable characteristics of the models. **Table 1** and **Table 2** give data distribution. The Churn risk model is divided into 3 main customer segments: Single-line, 2-5-Line, 6-15-

Line. Single Line Customers were grouped as "Uncommitment", "Commitment 0 - 90 Days" and "Commitment Over 90 Days", and a total of 5 different churn risk models were developed.

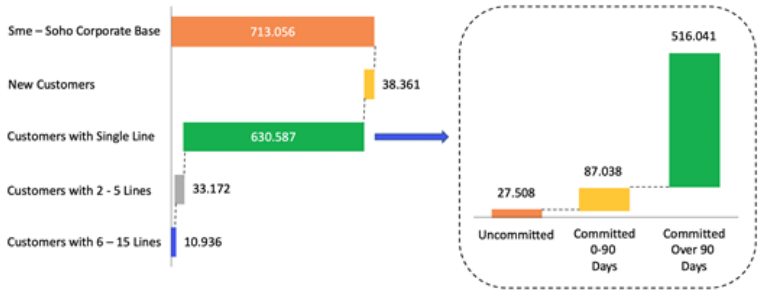

Figure 2. *Learning/ Sme-Soho corporate mobile customers distribution.*

Table 1. *Model Split of Sme-Soho corporate mobile customers.*

Type	# of Customers
Uncommitted	27.508
0-90 Days	87.038
Over 90 Days	516.041
Single Line Total	630.587
2-5 Lines Customers	33.172
2-5 Lines Subscribers	99.758
6-15 Lines Customers	10.936
6-15 Lines Subscribers	92.443

Table 2. *Data based on May 2022 and churn rates over July, August 2022.*

Model Split	*Total Customer Number*	*Total Churn Number*	*Churn Percent*
Single Line/Uncommitted	27,508	2,790	10,14 %
Single Line/Committed 0-90 Days	87,038	14,932	17,16 %
Single Line/Committed Over 90 Day	516,041	10,443	2,02 %
2-5 Lines	33,171	1,705	5,14 %
6-15 Lines	10,936	807	7,38 %
Total	674,695	30,677	4,55%

a) Sme-Soho corporate mobile customer churn rates

Model Split	*Total Subscriber Number*	*Total Churn Number*	*Churn Percent*
Single Line/Uncommitted	27,508	2,790	10,14 %
Single Line/Committed 0-90 Days	87,038	14,932	17,16 %
Single Line/Committed Over 90 Day	516,041	10,443	2,02 %
2-5 Lines	99,758	4,264	4,27 %
6-15 Lines	92,443	4,994	5,4 %
Total	822,788	37,423	4,55 %

b) Sme-Soho corporate mobile subscriber churn rates

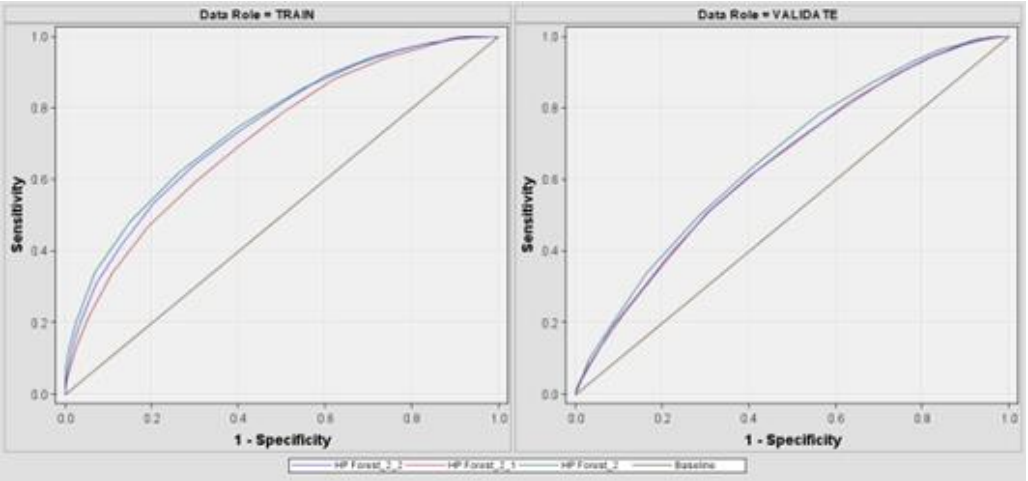

Figure 3. *Random Forest ROC Curves for Single Line Uncommitted Customers*

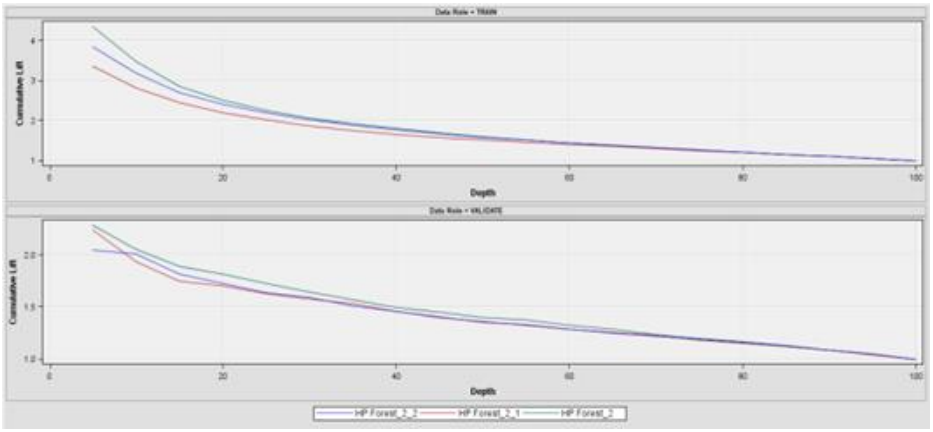

Figure 4. *Random Forest Cumulative Lift Curves for Single Line Uncommitted Customers*

5. Experimental Results

In this work, experimental results are presented by analyzing ROC curves, Cumulative Lift Curves, Churn graphics, and final Lift curves. Example results from the first split are given for each graphical analysis, whereas only ROC curves are given for the rest of the splits. This is the part of author's master thesis [27], in which details e.g. including codes, statistical analysis for all parameters, and detailed graphics can be found.

5.1. Prediction Model with Single Line / Uncommitted Customers

Fig.3, **Fig.4** and **Fig. 5** depict the experimental results. The train ROC Index value of the HP Forest model is 0.754, and the valid ROC Index value is 0.662. It is seen that it is higher than the other models applied. Therefore, Random Forest (HP Forest_2) method is chosen for churn estimation of Single Line Uncommitted customers. When the Decision Tree and Gradient Boosting model are compared, the highest ROC Index value is 0.721 which is below Random Forest.

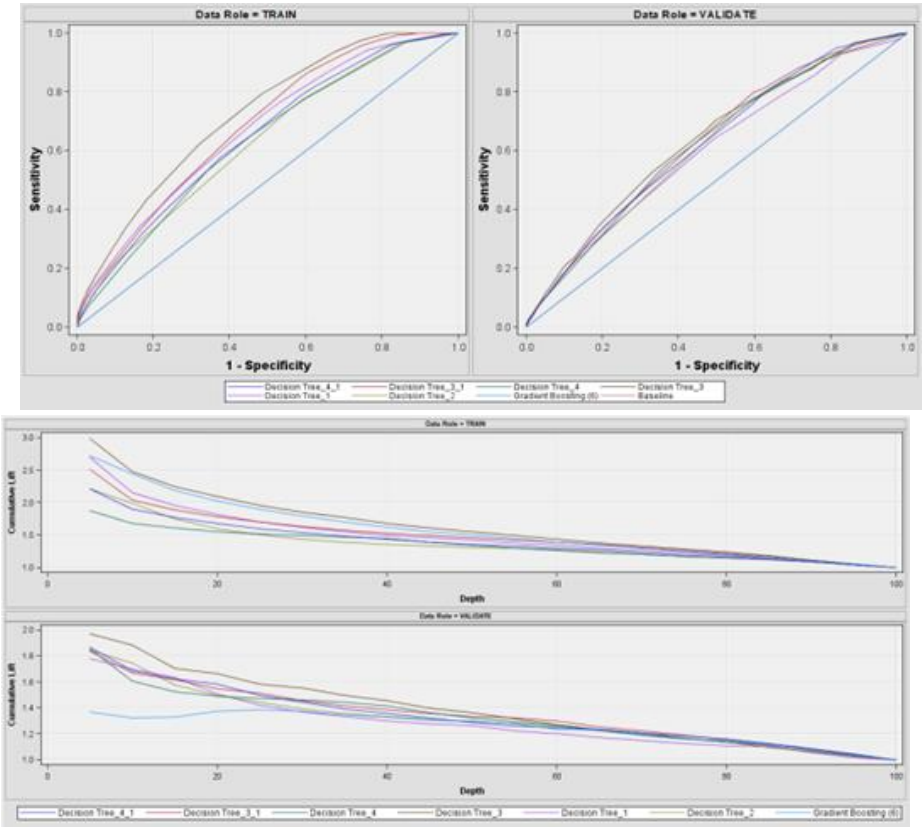

Figure 5. *Decision Tree and Gradient Boosting ROC and Lift Curves for Single Line Uncommitted*

Fig. 6 and **Fig. 7** present two important curves for this customer split, where the first one shows churn graphic in this split and the second one shows the Lift graphic. Therefore, these models are not used as churn forecasting models of single-line uncommitted customers. This split has a total of 27,508 subscribers and 2,790 churn. When the 5 percent slice is reached in line with the risk score, a total of 1,375 subscribers are reached. This corresponds to 9.8 % of the churn for the split. Lift is seen as approximately 2. The probability of catching churn is observed as 19.85.

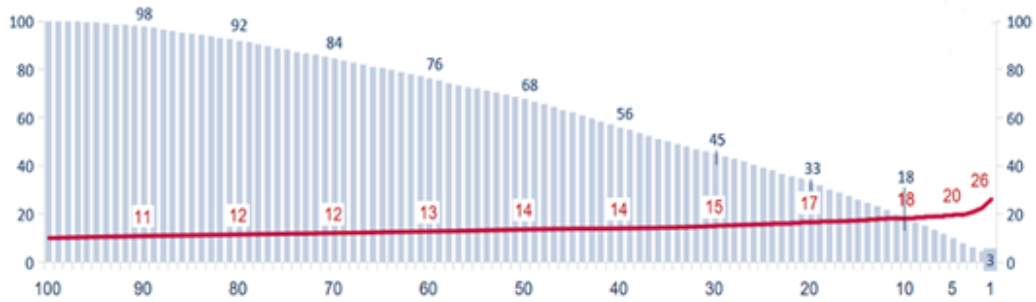

Figure 6. *Churn Graphic for Single Line Uncommitted Customers (Final Random Forest)*

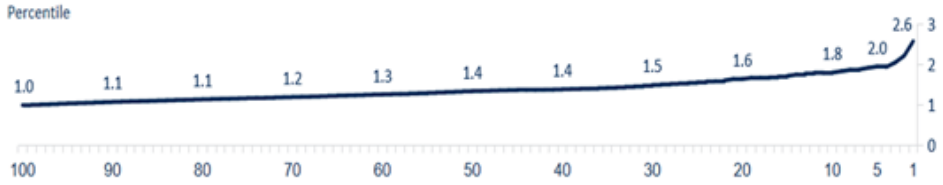

Figure 7. *Lift Curve for Single Line Uncommitted Customers (Final Random Forest)*

5.2. Prediction Model with Single Line / Committed 0 – 90 Days Variables

When the results of the applied machine learning models are compared, the highest Train:ROC Index value is Decision Tree_7 with a value of 0.686. The values of other machine learning models are below the Decision Tree_7 ROC Index. Train:Gini Coefficent value is 0.371, Train:Kolmogorov Smirnov Statistics value is 0.263, with the highest value compared to other models. Train:Cumulative Lift value is 2.216812. Therefore, Decision Tree_7 model was chosen for Single Line / Committed 0-90 Days customers. There are a total of 87,038 subscribers and 14,932 churn in this split. A total of 4,351 subscribers are reached when the 5 percent slice is reached in line with the risk score. This corresponds to 11.14 % of the churn for the split. Lift is seen as 2.22. The probability of catching churn is observed as 38.22.

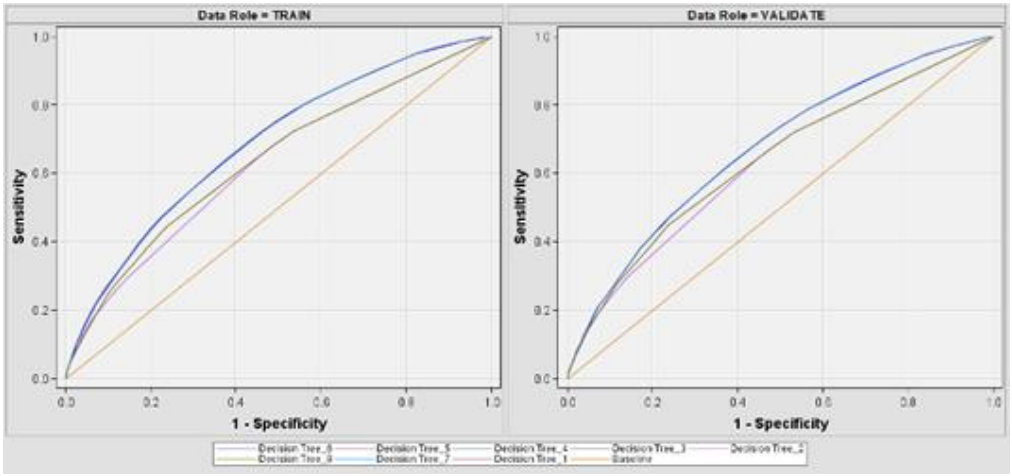

Figure 8. *ROC Curves for Single Line / Committed 0 – 90 Days Variables (Decision Tree)*

5.3. Prediction Model with single line/committed over 90 days customers

The highest ROC Index value is given for Regression (2) with a value of 0.749. Although the Regression (2) model gives better results than the other applied models, the lift of the Decision Tree_1 model is 3.9. The

results of the Decision Tree _1 model give better results compared to other models. Therefore, Decision Tree_1 model is chosen for the churn estimation of Single Line / Committed Over 90 Days customers. This split has a total of 516,041 subscribers and 10,443 churn. When the 5 percent slice is reached in line with the risk score, a total of 25,802 subscribers are reached. This corresponds to about 20% of the churn. Lift is seen as 3.9. The probability of catching churn is observed to be 7.9.

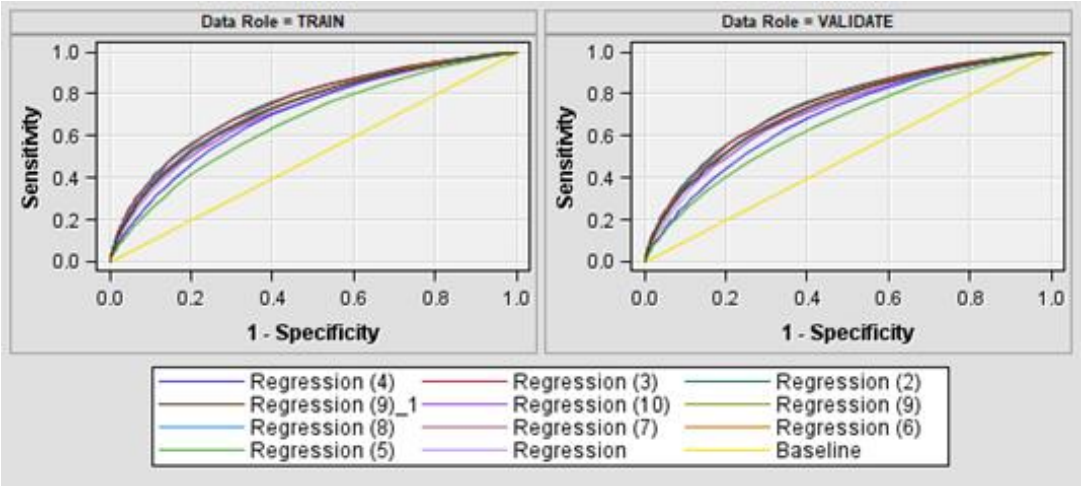

Figure 9. *ROC Curves for Single Line / Committed Over 90 Days Variables (Regression)*

5.4. Prediction Model with 2-5 Lines Customers Variables

When the results of the applied Gradient Boosting models are compared, the highest ROC Index value is 0.766. Therefore, Gradient Boosting is chosen for loss estimation of 2-5 Line customers. This split has a total of 33.172 customers and a total of 99.758 subscribers. 1.705 of these customers have churned and this corresponds to 4.264 cancellations on a subscriber basis. When the 5 percent slice is reached in line with the risk score, a total of 1,658 customers are reached, which corresponds to a total of 4,987 subscribers. For the 5 percent slice in this split, it corresponds to 24.44 % of churn on subscriber basis. The lift is seen as 4.9 on subscriber basis and the probability of catching churn is observed as 20.89.

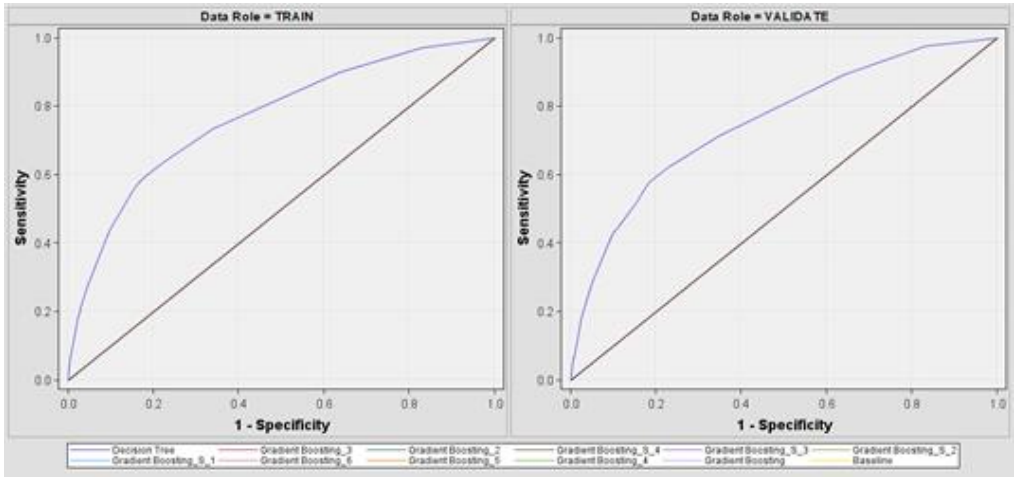

Figure 10. *ROC Curves for 2-5 Lines Customers Variables (Gradient Boosting)*

5.5. Prediction Model with 6-15 Lines Customers Variables

When the results of applied Regression & Gradient Boosting models are compared as in **Fig. 11**, Regression_5_1 Train: ROC Index value has the highest ROC index with 0.737, which is the highest values compared to other regression models. Therefore, Regression_5_1 model is chosen for loss estimation of Line 6-15 customers.

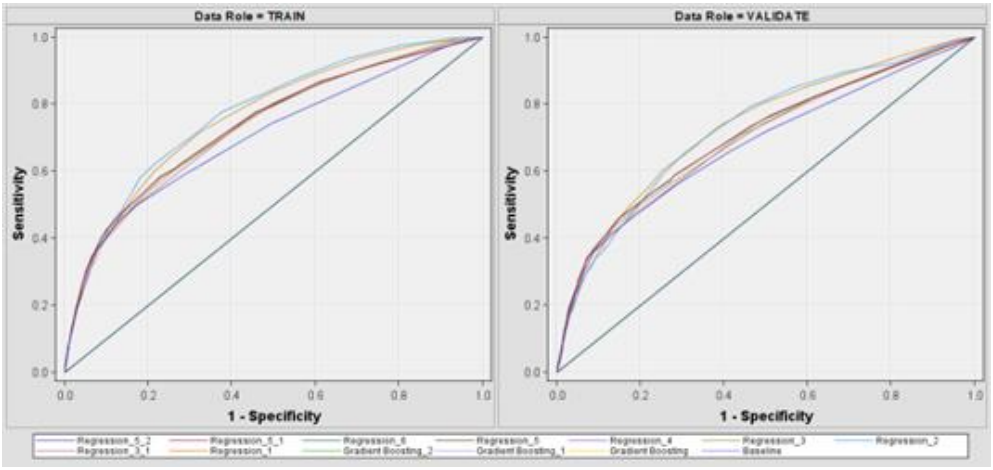

Figure 11. *ROC Curves for 6-15 Lines Customers Variables (Regression&Gradient Boosting)*

When the results of the applied Decision Tree models are compared as in **Fig. 12**, Decision Tree_3 Train:ROC Index value is 0.745 and although it has the highest ROC index, it is not chosen because its Cumulative rise is lower than the Regression_5_1 model. This split has a total of 10.936 customers and a total of 92.443 subscribers corresponding to this customer. 807 of these customers have churned and this corresponds to 4,994 cancellations per subscriber. When the 5 percent slice is reached in line with the risk score, a total of 546 customers are reached, which corresponds to a total of 4.622 subscribers. For the 5 percent slice in this split, it corresponds to 24.42 percent of churn on subscriber basis. On a subscriber basis, the lift is seen as 4.9 and the probability of catching a churn is observed as 26.40.

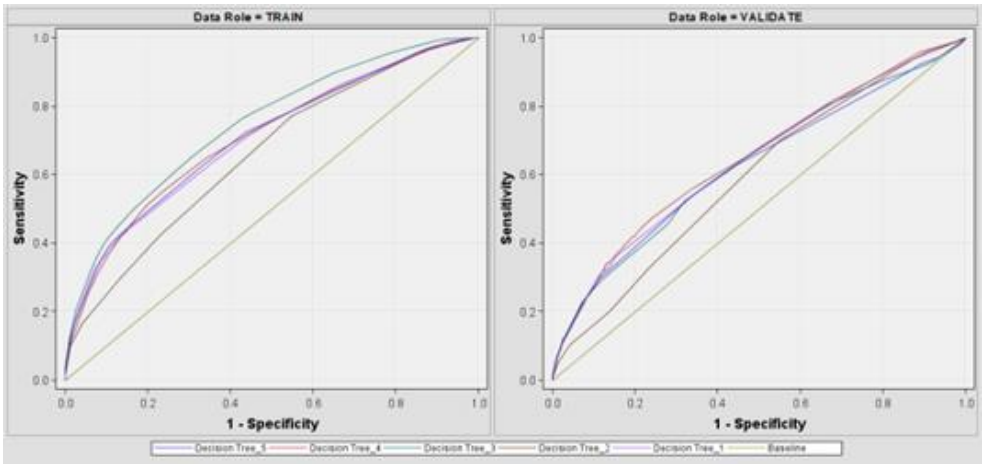

Figure 12. *ROC Curves for 6-15 Lines Customers Variables (Decision Tree)*

6. Discussion and Conclusions

The main purpose of this project is to find the best model to predict customer churn in the Telecommunications industry with machine learning models. Important variables are determined with descriptive data analysis and used in Single Line, 2-5 Line, and 6-15 Line customer models. The target variable is CHURN. For the single line uncommitted model, customers with lines 2-5 and 6-15 were eliminated from the data. The experiments show that HPDMForest method implemented in SaS gives the best results. For single line committed 0-90 Days customers data, decision tree is shown to be the most suitable model in line with the risk score, when the 5 percent slice is reached, a total of 4,351 subscribers are reached and this corresponds to 11.14 percent of the churn for the split. The lift is seen as 2.23, the probability of catching churn is observed as 38.22. Regression and decision tree machine learning methods are applied for Single Line Over 90 Days customers. Decision Tree gives the best results in line with the Single Line Over 90 Days risk score as the 5 percent slice is reached, a total of 25,802 subscribers are reached, and this corresponds to approximately 20 percent of the churn for the split. Lift is seen as 3.9, the probability of catching churn is observed as 7.9.

Gradient Boosting and Decision Tree machine learning algorithms have been applied for 2-5 Line Enterprise customers. In this split, for the 5 percent slice, it corresponds to 24.44 percent of the churn on a

subscriber basis. On the basis of subscribers, the lift is seen as 4.9 and the probability of catching churn is observed as 20.89. The regression model is chosen as the most suitable model for customers with 6-15 lines by after evaluating regression, gradient boosting, decision tree methods. In this split, for the 5 percent slice, it corresponds to 24.42 percent of the churn on a subscriber basis. On the basis of subscribers, the lift is seen as 4.9 and the probability of catching churn is observed as 26.40. This work demonstrates the potential application of major ML methods for successful churn prediction. It shows that there is no single method for all customers. The best approach is smart categorization of customers depending on usage period and type.

To further expand the dataset, the dataset can be expanded by adding parameters from the call center. For example, the number of times the agent calls the customer and the difference between the last call and the cancellation date can be included in the data set. In addition to the estimation of customer churn, the effectiveness of the call center can also be measured. Other parameters can be included in the dataset, taking into account business requirements. Depending on the dataset, this model will be more department specific. For example, loss estimation is often considered a scope of marketing analytics but call centers that call collections can use these formulas. To some extent, after the recent coronavirus outbreak, customers are using online channels more often than before, and call centers are becoming more important than before. A data set can be created that includes whether the customer has paid and continued to use the existing service provider or has disabled the service.

Declaration of interest

The authors declare that there is no conflict of interest.

Acknowledgement

This study is implemented in collaboration with marketing intelligence department of Turk Telekom, one of Turkey's largest telecommunication company during Buse Demir's master studies in Bahcesehir University.

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