



T.C. ESKİŞEHİR OSMANGAZİ ÜNİVERSİTESİ
MÜHENDİSLİK ve MİMARLIK FAKÜLTESİ DERGİSİ

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A NEW MODEL ON BENTHIC FORAMINIFER IMAGE CLASSIFICATION AND DEFINITIONS BASED ON CONVENTIONAL NEURAL NETWORK (CNN)

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Geology,
Benthic Foraminifera,
Classification,
Deep Learning,
Convolutional Neural
Networks

Abstract

*Fossil studies are of great importance in observing the changes in living species over time, making inferences using information from observed species, and understanding the evolving structure of our world. However, the examination and interpretation of fossil specimens is a complex and lengthy process. Artificial intelligence (AI) studies are now being applied to this field to facilitate the working methods of paleontologists. By aiding the detection and image classification of fossil specimens, computers simplify this process in comparison to manual classification and reduce foreign dependency on fossil assemblages that paleontologists are not experts in. To achieve this, images of 9 benthic foraminiferal species were used: *Bulimina tenuata*, *B. pagoda*, *Bolivina argentea*, *Bo. seminuda*, *Bo. spissa*, *Bo. subadvena*, *Epistominella smithi*, *Trifarina bradyi*, and *Takanayanagia delicata* from the MD022508 benthic foraminifera dataset of the publicly available Endless Forams, alongside ordinary non-foraminiferal photographs. A single study available on the same dataset presents a study that uses deep convolutional neural networks for image classification and description of benthic foraminifera with ready-made models from the literature. In this study, a new method has been developed that achieves high accuracy rates with new models on the same dataset. At least 70% accuracy rates were achieved in the test results of the system trained with this method. This study, which reached high accuracy rates with a new method, presents a successful development for the branch of paleontology in the use of AI in microfossil identification.*

BENTİK FORAMİNİFER GÖRÜNTÜ SINIFLAMASI VE TANIMLAMALARINDA EVRİŞİMLİ SİNİR AĞI (CNN) TABANLI YENİ BİR MODEL

Anahtar Kelimeler

Jeoloji,
Bentik Foraminifer,
Sınıflandırma,
Derin Öğrenme,
Evrışimli Sinir Ağları

Öz

*Canlı türlerinin yıllar içindeki değişimini gözlemlemek, gözlemlenen türlerin sağladığı bilgilerden yararlanarak çıkarımlarda bulunmak ve içinde yaşadığımız dünyanın yıllar içinde gelişen ve değişen yapısını anlamak için fosil çalışmaları büyük önem taşımaktadır. Ancak fosil örneklerinin incelenmesi ve yorumlanması karmaşık ve uzun bir süreçtir. Paleontologların çalışma yöntemlerini kolaylaştırmak için yapay zeka çalışmaları bu alana uygulanmaya başlandı. Fosil örneklerinin bilgisayar yardımıyla tespiti ve görüntü sınıflandırılması, bu işlemi manuel sınıflandırma işlemlerine kıyasla mümkün olduğunca basitleştirir ve paleontologların uzman olmadığı fosil toplulukları için dışa bağımlılığı azaltır. Bunu başarmak için, seçilen bir veri setinden Halka açık Sonsuz Foram MD022508 bentik foraminifer veri kümesinden *Bulimina tenuata*, *B. pagoda*, *Bolivina argentea*, *Bo. seminuda*, *Bo. spissa*, *Bo. subadvena*, *Epistominella smithi*, *Trifarina bradyi* ve *Takanayanagia* gibi 9 bentik foraminifer türünün görüntüleri ve sıradan foraminifer olmayan fotoğraflar kullanıldı. Aynı veri seti üzerinde mevcut olan tek bir çalışmada, derin evrışimli sinir ağları kullanılarak bentik foraminiferlerin görüntü sınıflandırılması ve tanımlamaları için geliştirilen ve literatürdeki hazır modellerle çalışılmış bir çalışma mevcuttur. Bu çalışmada, aynı veri seti üzerinde*

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geliştirilmiş yeni modellerle yüksek doğruluğa ulaşan yeni bir yöntem sunulmaktadır. Bu yöntemle eğitilen sistemin test sonuçlarında en az %70 doğruluk oranlarına ulaşılmıştır. Yeni bir yöntemle yüksek doğruluk oranlarına ulaşan bu çalışma, mikrofosil tanımlamada yapay zeka kullanımında paleontoloji dalı için başarılı bir gelişme olmuştur.

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1. Introduction

Microfossils are generally small-sized fossils whose distinctive features are best studied with a microscope. They may contain a heterogeneous group of organism fossils of microscopic size, such as foraminifera, ostracoda, and radiolaria. Among these, foraminifers are a group of microorganisms that have been extensively studied worldwide. They are characterized by flowing granular ectoplasm, often supported by a so-called "test" shell. These microorganisms have a wide geographical distribution under the benthic and pelagic conditions of marine environments, with rich genera and species throughout the Phanerozoic era, and are single-celled animal creatures from the Cambrian to the present day (Platon and Gupta, 2001; Sakıncı, 2008). Most of the niches of foraminifera are marine and stenohaline, although certain groups can survive under hypersaline conditions. Some species prefer low saline waters and are often found in brackish lagoons and estuaries (Saraswati and Srinivasan 2015). About 50,000 species of this group have been described, of which more than 4,000 species live today (Pawlowski, Esling, Lejzerowicz, Cedhagen, and Wilding, 2014).

Their shells are mostly calcareous, but a few may be pseudo-chitinous, agglutinated, or rarely siliceous. Their size varies between about 0.1 mm and 10 cm. Species and genera are distinguished by their morphological features.

Identifying among tens of thousands of genera and species in the literature requires both experience and dominance of the literature, and a highly sensitive study in order to clearly extract each feature of the fossil. Many paleontologists therefore specialize in only one group or one period. As a result of the existence and coexistence of many fossil groups, paleontologists feel obliged to seek support from each other for the identification of each group, or they leave the fossil only by describing it on the basis of its branch or family. Considering that each sub-fossil group has an expert on the foraminifers of each geological time, and even each foraminiferal genus, it is clearly seen that the discipline of foraminifera is shaped by the dominant success of individual experiences. For this reason, the research of a paleontologist working anywhere can sometimes depend on the knowledge of a paleontologist living in a different part of the world. One of the biggest potential benefits of this project is that it has the potential to serve as the heir of the experiences of valuable scientists,

independent of the human factor, sourced from the common data accumulation for the field of paleontology, which is shaped by personal skills and experiences. Until recently, paleontological knowledge and experiences have been transferred to the digital environment in a limited way around the world. The directing of artificial intelligence applications, which are already very advanced, to this field is limited (Parab and Mehendale, 2021; Putzu, Caocci and Di Ruberto, 2014; Pan et al., 2020; Liao, Li and Luo, 2016; Zeggada, Benbraika, Melgani and Mokhtari, 2018; Wu and Prasad, 2017 etc.). It is thought that these developments will reduce the inaccessibility and/or foreign dependency on paleontology studies, and contribute to these studies with rapid support by using developing technology methods since it is an up-to-date idea. By collecting the data in the literature and developing correct detection methods, objective, measurable and developable microfossil identification studies can be achieved with artificial intelligence studies. Artificial intelligence is in a very good place at the moment in image identification. These studies have also begun on fossils (Zhong, Ge, Kanakiya, Marchitto and Lobaton, 2017; Ge, Zhong, Kanakiya, Mitra, Marchitto and Lobaton, 2017; Xu, Dai, Wang, Li and Wang, 2020; Mitra et al., 2019; Gutiérrez, Nouboud, Chalifour, and Voisin, 2018; Johansen and Sørensen, 2020; Hu, Limaye and Lu, 2020; Carvalho et al., 2020). It is developing more and more every day.

The aims of the paper are to reduce foreign dependency, save time, and create more reliable, accessible and easy-to-use software for researchers studying different time periods and different fossil groups.

In this study, experiments on the image classification of fossil specimens are described. The classification process was carried out using an algorithm trained with data obtained from segmented fossil views as training items in deep learning methods (Convolutional Neural Network). Physical properties, such as the number of chambers, dimensions, openings, and shape of the fossil specimen, are essential parameters for classification. A dataset containing different images of benthic foraminifers is required. The MD022508 benthic foraminifera dataset, publicly available in Endless Forams (Hsiang et al. 2019), was selected to train the model. The dataset used in this project is the Endless Forams image set, which includes 13 different benthic foraminifera species and also planktic foraminiferas,

particles, and fragments (Marchant, Tetard, Pratiwi, Adebayo, and Garidel-Thoron, 2020). From this dataset, nine benthic species and non-foraminifer images were selected to train and test the model. These species are *Bulimina tenuata*, *B. pagoda*, *Bolivina argentea*, *Bo. seminuda*, *Bo. spissa*, *Bo. subadvena*, *Epistominella smithi*, *Trifarina bradyi*, and *Takanayanagia delicata*. The data of the selected species are divided into three different groups: 10% testing, 20% validation, and 70% training. As a result of the ongoing training process, when the trained system is tested with a new fossil sample, it aims to determine which genus the sample belongs to. With the proposed method, at least 70% accuracy rates were achieved in the test results of the trained system. This study, which achieved high accuracy rates with a new method, has created a successful development for the branch of paleontology in the use of artificial intelligence in microfossil identification.

In the following parts of the article, the method of the study is explained after previous studies in the literature are mentioned. This section explains the stages of preparing the dataset, setting up the model architecture, and the interface of the systems. The results section includes the convolutional neural network, classification, and conclusions.

2. Literature

Although there have been several online databases, presentations (Loeblich and Tappan, 1994; Foraminifera.eu; WoRMS Editorial Board, 2023), and a few software studies on foraminifera (Görmüş and Meriç, 2012; Deveciler and Akiska, 2018) in the literature, the description of foraminifera using the CNN method has not been well-documented. In fact, neural networks can be used in many areas, including geology for classifying fossil specimens, fossil segmentation and detection, and more (Zhong et al. 2017; Ge et al. 2017; Xu et al. 2020; Mitra et al. 2019; Gutiérrez et al. 2018; Johansen and Sørensen, 2020; Hu et al. 2020; Carvalho et al. 2020).

According to the study, pictures of six different species of foraminifera were taken with a microscope under 16 different controllable LED lights. A three-dimensional image was obtained by taking the maximum, minimum, and average values of the 16 images photographed. The combined images were used as input in a CNN network previously trained using a model formed from the combination of VGG16, ResNet50, and Inception V3 algorithms. For the classification process, the SVM classification method was used to conclude the process. A similar study (Ge et al., 2017) observed images of six different foraminifera species recorded under 16 different light microscopes for foraminifer segmentation. The main lines were created with the developed edge detection algorithm. After passing the views through the edge detection process, 128 deep

feature maps were combined using the CNN method, and segmented images were obtained. The described method for recognizing paleontological paintings involves scaling the images to grayscale, adjusting brightness and contrast, and sharpening the images. Scale-invariant Feature Transform (SIFT) is used to find feature points and feature vectors for the pre-prepared images. K-means clustering is then used to find the distance between vector sets and feature points, and new centers are obtained according to the distribution of objects. For the nonlinear binary classification of feature vectors completed with clustering, classification is performed using SVM (Xu et al., 2020). Another study used 7 different species for the recognition of planktic foraminifers, and the images were used in the training of the CNN structure. The image was then estimated with ResNet50 and Vgg16 (Mitra et al., 2019). The article also describes a segmentation technique developed for use in diatom classification. The segmentation technique involves finding two thresholds on either side of the dominant pile using both the Rosin method and the approximate determination of the cumulative distribution function with the sigmoid function. The histogram consists of the cumulative distribution function and the sigmoid cumulative distribution function. The points where the vertical, two parallel lines drawn from the start and end points of the SCDF's vertex cut the CDF were determined as the threshold values. Thus, the value between the two thresholds is 0, and the values outside this threshold are 255. Afterwards, all connected components in the image are labeled, and the largest is determined. Then, the size of each component is normalized to the area of the largest convex shell. The minimum Euclidean distance between the largest component and the others is then calculated, and diatom reconstruction is done with the obtained data, thus removing diatoms from the background (Gutiérrez et al., 2018). In a similar study, smaller images of each sample were extracted using a simple but effective object detection scheme based on Gaussian filtering, grayscale thresholding, binary masking, and connected components. The first pass of Gaussian filtering, grayscale thresholding, and binary masking is set to remove the metallic border present in each image. Using a pre-trained VGG16 model, feature vectors were extracted from each of the foraminifer and sediment images in the dataset, and stochastic estimation was made with Monte Carlo Dropout (Johansen and Sørensen, 2020). The study also describes Dishti, a developed three-dimensional segmentation software that combines computer tomography data to create three-dimensional visuals and enables their segmentation (Hu et al., 2020). The tomography data is reconstructed with software called Mango. Another study on this subject mentions the identification process where microfossils are found directly with a pipeline developed. The developed system starts with the digitization of carbonic rocks.

Afterwards, the images obtained with microCT are respectively; quarter, half and full scale. The system was trained using the UNET model associated with ResNet34 and segmentation was performed (Carvalho et al., 2020).

3. Methods

Obtaining a reliable and open access dataset is the most important step in the methodology of this study. Therefore, the Endless Forams dataset was chosen for this purpose, and tests and validations were performed on selected species from this dataset. Convolutional Neural Networks were used to train the model, and in order to achieve high precision in the classification process, the CNN Model was selected and the training process was initiated. The paper has been prepared in accordance with research and publication ethics.

3.1. Dataset Preparation

The dataset is an essential part of training the neural network model. It needs to be properly split and labeled. For this purpose, the Endless Forams dataset was used, which meets the requirements for training the model with thousands of benthic and planktonic foraminifera images. The foraminifera views in the dataset were bright images, and a binary segmentation mask was applied to reduce the effect of brightness (Marchant et al. 2020). From this dataset, 9 species were selected to train and test the model, namely *Bulimina tenuata*, *B. pagoda*, *Bolivina argentea*, *Bo seminuda*, *Bo. spissa*, *Bo. subadvena*, *Epistominella smithi*, *Trifarina bradyi*, and *Takanayanagia delicata* as shown in Figure 1.

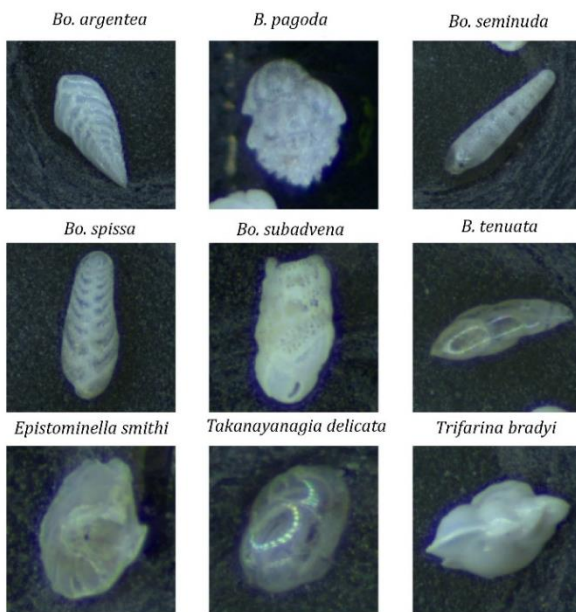


Figure1. Views of The Training Species

The data for the selected species was divided into 3 different groups: 10% for testing, 20% for validation, and 70% for training. The test and validation images were separated from the total amount of images according to the ratios mentioned earlier. To create the training set, folders were created for each species in an empty folder, and each folder was named after the corresponding species. All specimens were then separated from each other based on their species and brought together in these folders. The main folder containing all the species folders was named "training". The same process was repeated for the test and validation sets. All three main folders were then collected in another folder, concluding the dataset preparation process.

3.2. Model Architecture

To train the model, a custom convolutional neural network has been developed. Although pre-trained models might provide a faster solution, custom CNNs allow for a larger degree of network customization according to the specific purpose. The edited and tagged dataset is used, and the images are resized prior to feature extraction to a target size of 200x200. A batch size of 64 is selected. To use the feature extractions obtained from the images in CNN training, the images are divided into pixels using the Image Data Generator, a Keras function. The pixel values are scaled from 0 to 1 by dividing them by 255. This is necessary to obtain the data necessary for training the CNN model. Since the classification process will involve multiple classes, the categorical classification method is used, with the labels enumerated from zero to nine. The data used for the CNN model has now been appropriately formatted for training the model.

The CNN was chosen as the neural network to be used because high precision is needed in the classification process. CNN offers much higher precision than ANN structures due to the layers and filters it contains. In the created model, the first block is formed by a 3x3 convolutional layer. The following layer is a 2x2 pooling layer, thus forming the first block. The Convolution layer contains rectified linear (ReLU) activation. As a result of the tests, it has been observed that when the number of blocks in the model is below four, an underfitting problem occurs. Therefore, three blocks of the same structure were added following the first block. The data coming out of the neural network formed between the blocks is smoothed, and the overfitting situation is aimed to be reduced by applying dropout. Following the dropout layer, a density layer of 512 units and ReLU activation is placed. The last density layer has softmax activation and 9 units. Since 9 classes are used in the CNN model, the final density layer consists of 9 units. The representation of the model architecture is shown in Figure 2.

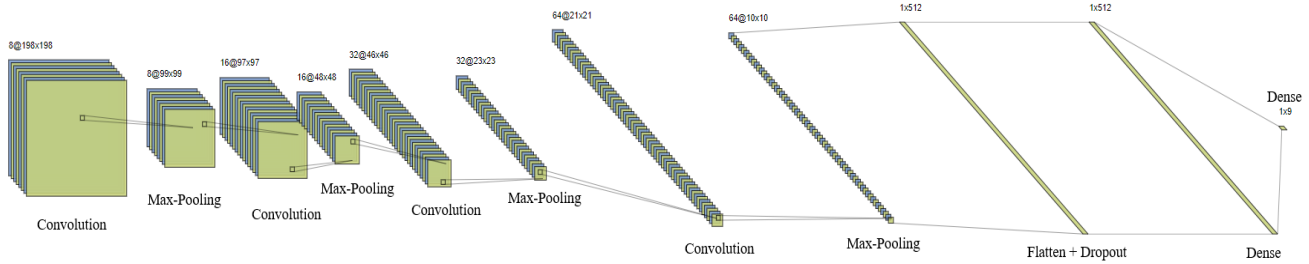


Figure 2. The Representation of The CNN Model

The training of the system was initiated using the created CNN model. CNNs are trained using categorical cross-entropy loss, which is utilized due to the implementation of the categorical classification technique as the classification mode. To update the parameters of the network, Adam (Adaptive Moment) optimization is employed. The tables below illustrate the other models developed.

3.2. Interface of The System

To simplify the process of finding the optimal system, an interface was developed. The interface allows the user to change specific hyperparameters to train the model. The interface consists of parameters such as the number of epochs, steps per epoch, batch size, image size, and the percentage of the test split of the image set. The user can input the desired parameter values via the keyboard. Upon clicking the start button, the training process of the defined model begins. The interface is shown in Figure 3.

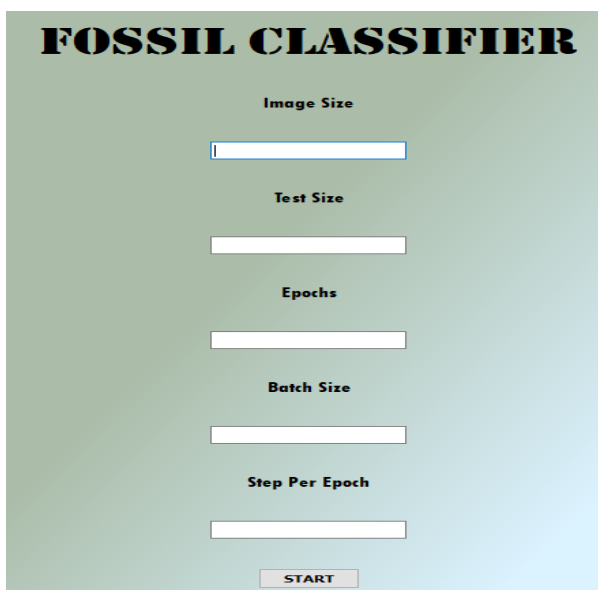


Figure 3. Interface of The Model

4. Results

To find the optimal CNN model, many training sessions were carried out using the Endless Forams image set. This dataset contains the following species: *B. tenuata*, *Bo. argentea*, *B. pagoda*, *Bo. seminuda*, *Bo. spissa*, *Bo. subadvena*, *E. smithi*, *T. bradyi*, and *T. delicata*. The number of views for each species used to train the model are as follows: *B. tenuata* (357 views), *Bo. argentea* (236 views), *B. pagoda* (44 views), *Bo. seminuda* (778 views), *Bo. spissa* (255 views), *Bo. subadvena* (180 views), *Epistominella smithi* (92 views), *Trifarina bradyi* (41 views), and *Takanayanagia delicata* (365 views), as shown in Table 1.

Table 1: Fossil Sample Numbers and Percentage

<i>Fossils</i>	Number of views	Number of views (%)
<i>B. tenuata</i>	357	15,2
<i>Bo. argentea</i>	236	10,05
<i>B. pagoda</i>	44	1,87
<i>Bo. seminuda</i>	778	33,13
<i>Bo. spissa</i>	255	10,86
<i>Bo. subadvena</i>	180	7,67
<i>Epistominella smithi</i>	92	3,92
<i>Trifarina bradyi</i>	41	1,75
<i>Takanayanagia delicata</i>	365	15,55
Total	2348	100,0

The training and testing of the system were conducted using Tensorflow 2.5.0 with GPU enabled and Python 3.9. The computer used for training runs on Windows 10 with an AMD Ryzen 5 3600 CPU, NVIDIA RTX2060 GPU, and 16 GB RAM.

4.1. Convolutional Neural Network

To achieve the best accuracy results, the CNN model was tested multiple times as shown in Table 2. To automate the testing process, a Python loop was written to increase the specific parameter at the end of the training. The convolutional layers in the following sentences are denoted by 16C3, where 16 represents the number of filters and 3 represents the 3x3 kernel size. The max pooling layer is denoted by P2, where 2 is the size of the kernel, which is 2x2. First of all, the number of blocks is handled. The testing started with [16C3-P2]-128-9 CNN, and at every step of the test, the feature extraction blocks were increased and the number of filters doubled at every new block. The best results were obtained with [8C3-P2]-[16C3-P2]-[32C3-P2]-[64C3-P2]-1024-9, which means using 4 blocks for the convolutional layer. Other results encountered the

overfitting problem more than the obtained model. From the initial test, the training accuracy of the system was obtained as 0.65 and the validation accuracy of the system was obtained as 0.52.

After conducting a parametric analysis, it can be observed that the best results were obtained when initially using 8 filters for the first convolutional layer. These results are shown in Table 3. Once the number of blocks and filters were determined, the units of the dense layer were adjusted. As shown in Table 4, the highest training accuracy and validation accuracy, 94% and 75%, respectively, were obtained when the number of units was set to 1024. To reduce overfitting, a dropout layer was added to the CNN model. However, as shown in Table 5, adding a dropout layer led to overfitting during the model training. To overcome this situation, the extra dropout layers were removed, and only one dropout layer was left before the output dense layer. The results indicate that adding dropout does not fit well with this neural network model. After conducting these experiments, it is clear from the tables that the optimum CNN structure for this work is as follows: [8C3-P2]-[16C3-P2]-[32C3-P2]-[64C3-P2]-1024-9.

Table 2. Number of Convolutional Layers and Max Pool Layers Comparison Table

Convolutional Layers	Epoch	Step	Batch size	Activation	Training Max. Acc.	Validation Max. Acc.
Single Block	100	10	64	Softmax	0.65	0.52
Two Blocks	100	10	64	Softmax	0.67	0.61
Three Blocks	100	10	64	Softmax	0.70	0.65
Four blocks	100	10	64	Softmax	0.87	0.70
Five Blocks	100	10	64	Softmax	0.82	0.67

Table 3. Number of Filters Comparison

Filters	Epoch	Step	Batch size	Activation	Training Max. Acc.	Validation Max. Acc.
8	100	10	64	Softmax	0.93	0.73
16	100	10	64	Softmax	0.90	0.72
32	100	10	64	Softmax	0.90	0.72
64	100	10	64	Softmax	0.89	0.72

Table 4. Dense Layer Unit Comparison Table

Fully connected Layer Unit	Epoch	Step	Batch size	Activation	Training Max. Acc.	Validation Max. Acc.
16	100	10	64	Softmax	0.81	0.69
32	100	10	64	Softmax	0.83	0.72
64	100	10	64	Softmax	0.81	0.70
128	100	10	64	Softmax	0.84	0.71
256	100	10	64	Softmax	0.86	0.71
512	100	10	64	Softmax	0.90	0.75
1024	100	10	64	Softmax	0.94	0.75
2048	100	10	64	Softmax	0.91	0.73

Table 5. Dropout Rate Comparison Table

Dropout	Epoch	Step	Batch size	Activation	Training Max. Acc.	Validation Max. Acc.
0.2	100	10	64	Softmax	0.81	0.59
0.3	100	10	64	Softmax	0.83	0.64
0.4	100	10	64	Softmax	0.78	0.70
0.5	100	10	64	Softmax	0.95	0.76
0.6	100	10	64	Softmax	0.90	0.67

4.2. Classification Results

The CNN model was tested using test images to measure its success in the classification process, as shown in Figure 2. The softmax activation function generated probabilities, which are percentage representations of the class to which the images belong. During the prediction process, an image may belong to more than one class, resulting in more than one probability value. However, the highest probability value is accepted as the result of the class to which the image belongs.

The Endless Foram dataset images were used to run the proposed model 15 times, and the experiment was concluded. The dataset was divided into 70% for training, 20% for validation, and 10% for testing. The average test accuracy for the Endless Foram images was 77%, with a precision of 74%, recall of 77%, and F-score of 75%. The detailed evaluation metrics are given in Table 6.

Table 6. Evaluation Metrics of Proposed Method

Evaluation Metrics of Proposed Method				
	Min.	Max.	Mean	Std. Deviation
Accuracy	0.75	0.79	0.77	0.017
Precision	0.70	0.78	0.74	0.021
Recall	0.75	0.79	0.77	0.017
F-Score	0.73	0.78	0.75	0.019

The minimum, maximum, mean, and standard deviation values in Table 6 represent the statistical data obtained from running the model 15 times. The test accuracy graph resulting from the 15 runs is shown in Figure 4.

The confusion matrix is a performance metric for machine learning classification that allows the visualization of the similarity between the correct class and the predicted class. The confusion matrix for the Endless Foram dataset is shown in Figure 5. It can be observed that the most accurate prediction was made during the classification of *Bo. seminuda*, while the most inaccurate prediction was made during the classification of the *B. Pagoda* species. *Bo. seminuda*

species can be predicted with high accuracy because it has a more distinguishable physical structure and a higher number of specimens in the dataset compared to other species. In the case of the *Pagoda* type, the situation is slightly different.

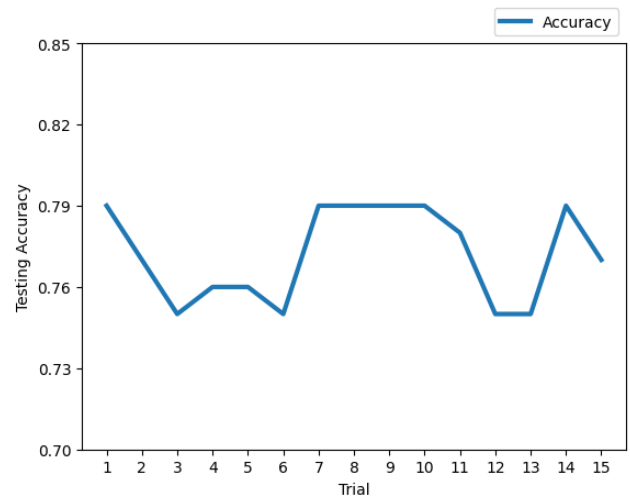


Figure 4. The Testing Accuracy Graph Obtained from Running the Proposed Method 15 Times

Although it has a different appearance from other species due to its physical structure, the scarcity of specimens in the dataset directly affects the model's learning. The abundance of data is of great importance during the training of a Neural Network for better results. Increasing the number of *Pagoda* specimens in the dataset can lead to more accurate predictions. The results of this study provide a basis for a potential study of adding developable code information on section directions, similar to the working methods of micropalaeontologists. Another potential benefit of this study is that it is a preliminary study for the paleontology discipline, which is shaped by personal skills and experiences, independent of the human factor, and takes its source from the common data accumulation. This study is a step forward in terms of inheriting the experience of scientists.

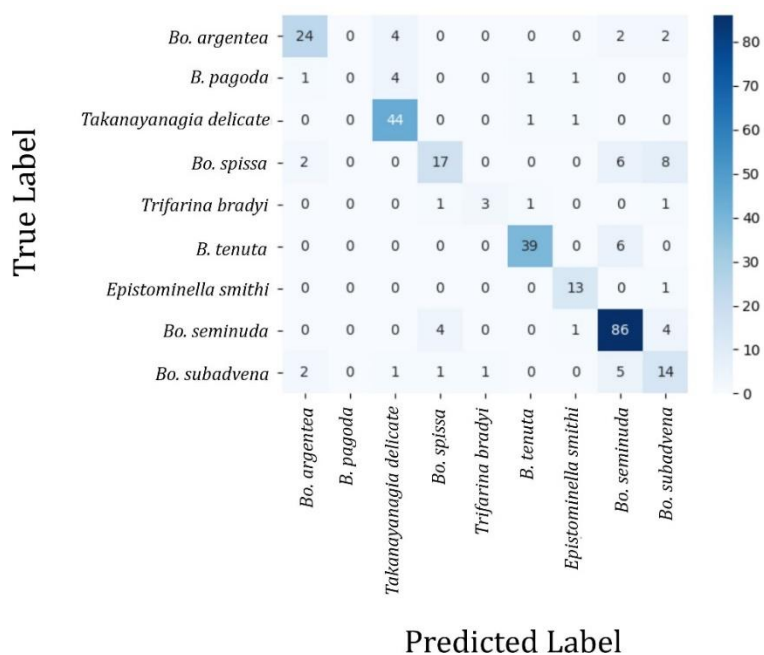


Figure 5. Confusion Matrix for Endless Forams Dataset

5. Conclusion

In this study, the CNN model developed for the classification of benthic foraminifera species and the results obtained are discussed. The main objective of this study was to create a CNN model that could classify microfossils, which are difficult to classify, more easily, quickly, and in a shorter amount of time. To achieve this, first, a dataset was created. The Endless Forams dataset was used for this purpose. The benthic foraminifera included in the Endless Forams dataset were first separated according to their species. Later, these types were divided into three main folders as training, testing, and validation folders. The training set was used to train the CNN model to be created, the validation set was used to determine the accuracy of the trained model, and the test set was used to test the operation of the created model. A lot of experimental work was done during the creation of the CNN model. As a result of the studies, it was observed that the model with four convolutional layers provided the best results. After obtaining the required model for classification, the necessary tests for the classification of the species were started. As a result of the tests, satisfactory results were obtained. Some species had higher accuracy, while others had lower accuracy. Based on the studies, it was concluded that this problem could be overcome by increasing the specimens of the species with low hit rates. When the general picture was evaluated, it could be said that the study was concluded successfully. Even though the designed model did not have enough data, it performed an acceptable classification process.

The results of this study provide a basis for potential research on the addition of developable code information on section directions, similar to the working methods of micropalaeontologists. Another significant potential benefit of this study is that it serves as a preliminary study for the field of paleontology, which is shaped by personal skills and experiences and independent of the human factor, drawing its source from common data accumulation. This study represents a significant achievement in terms of the legacy of scientific experience.

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Contribution of Researchers

In this study; Kübra YAYAN, identification of the problem, literature search, suitability of the data set, checking the output; Uğur YAYAN contributed to the production of suitable solution proposals for the problem, determination of working methods, explanation and control.

Conflict of Interest

No conflict of interest has been declared by the authors.

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MULTIPLE CLASSIFICATION OF BRAIN TUMORS FOR EARLY DETECTION USING A NOVEL CONVOLUTIONAL NEURAL NETWORK MODEL

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Keywords

Deep learning, CNN models, pre-trained models, brain MRI images, classification.

Abstract

Brain tumors can be dangerous and fatal if not diagnosed early. These are diagnosed by specialized doctors using biopsy samples obtained from the brain. This process is exhausting and wastes the doctors' time. Researchers have been working to develop a quick and accurate way to identify and classify brain tumors to overcome these drawbacks. Computer-assisted technologies are used to support doctors and specialists in making more efficient and accurate decisions. Deep learning-based methods are one of these technologies that have been used extensively in recent years. However, there is still a need to explore architectures with higher accuracies. For this purpose, in this paper, we propose a novel convolutional neural network (CNN) which has twenty-four layers to multi-classify brain tumors from brain MRI images for early diagnosis. Various comparisons and tests were performed to demonstrate the effectiveness of the proposed model. Three different state-of-the-art CNN models were used for the comparison: AlexNet, ShuffleNet, and SqueezeNet. At the end of training, the proposed model achieved the highest accuracy of 92.82% and the lowest loss of 0.2481. In addition, ShuffleNet achieved the second highest accuracy of 90.17%. AlexNet had the lowest accuracy at 80.5%, with a loss of 0.4679. These results demonstrate that the proposed CNN model provides greater precision and accuracy than state-of-the-art CNN models.

YENİ BİR EVRİŞİMLİ SİNİR AĞI MODELİ KULLANILARAK ERKEN TEŞHİS İÇİN BEYİN TÜMÖRLERİNİN ÇOKLU SINIFLANDIRMASI

Anahtar Kelimeler

Derin öğrenme, ESA modelleri, önceden eğitilmiş modeller, Beyin MR görüntüleri, sınıflandırma.

Öz

Beyin tümörleri erken teşhis edilmezse çok tehlikeli ve ölümcül etkilere sahip olabilir. Beyin tümörleri, uzman doktorlar tarafından beyinden alınan biyopsi örnekleri kullanılarak teşhis edilir. Bu süreç yorucudur ve doktorların çok fazla zamanını harcar. Araştırmacılar, bu dezavantajların üstesinden gelmek amacıyla beyin tümörlerini tanımlamak ve sınıflandırmak için hızlı ve doğru bir yol geliştirmeye çalışmaktadırlar. Doktorların ve uzmanların daha verimli ve doğru kararlar vermelerini desteklemek için bilgisayar destekli teknolojiler kullanılmaktadır. Derin öğrenme tabanlı yöntemler de bu teknolojilerden biridir ve son yıllarda yoğun olarak kullanılmaya başlanmıştır. Bununla birlikte, daha yüksek doğruluk performansına sahip mimarileri keşfetmeye hala ihtiyaç vardır. Bu amaçla, bu çalışmada erken teşhis için beyin MR görüntülerinden beyin tümörlerini çoklu sınıflandırmak için yirmi dört katmana sahip yeni bir evrişimli sinir ağı (ESA) önerilmiştir. Önerilen modelin etkinliğini göstermek için çeşitli karşılaştırmalar ve testler yapılmıştır. Karşılaştırmada üç farklı son teknoloji CNN modeli kullanılmıştır: AlexNet, ShuffleNet ve SqueezeNet. Eğitim sonunda önerilen model %92.82 ile en yüksek doğruluk ve 0.2481 ile en düşük kayıp elde edilmiştir. Ek olarak, ShuffleNet %90.17 ile ikinci en yüksek doğruluk değerine ulaşmıştır. AlexNet, 0.4679 kayıpla %80.5 ile en düşük doğruluğa sahiptir. Bu sonuçlar, önerilen CNN modelinin, son teknoloji CNN modellerinden daha fazla kesinlik ve doğruluk sağladığını göstermektedir.

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1.Introduction

In recent years, convolutional neural network (CNN) has been used effectively in many applications. These are classification (Fu, Zang, He, Cao, Guo & Wang, 2022; Inik, Uyar, & Ülker, 2019; Mao, Yin, Zhang, Chen, Chang, Chen, Yu & Wang, 2022; Zhou, Wang, & Wan, 2022), detection (Gonçalves, Souza & Fernandes, 2022; Inik & Ulker 2022; Kaya, Kurt, Isik, Koca & Cicek, 2022; Li, Dong, Wen, Hu, Zhou & Zeng, 2019; Zhao, Liu, Yin & Wang, 2022), and segmentation (Fradi, Zahzah & Machhout, 2022; Inik & Ulker 2022; Kang, Zhou, Huang & Han 2022; Karthik, Menaka & Won 2022; Niyas, Pawan, Kumar & Rajan, 2022). CNN-based methods have started to be used extensively in the diagnosis of brain tumors due to their high success in solving different problems.

Brain tumors are anomalies that occur when brain cells proliferate at an abnormal rate. The most common types of brain tumors include meningiomas, gliomas, and pituitary tumors. Radiologists use their skills to identify and categorize brain tumors, which is a complex and time-consuming procedure. Computer-assisted technologies are used to help doctors and experts to operate more efficiently and make more accurate decisions. Artificial intelligence is becoming increasingly useful in identifying and classifying brain tissues as contemporary medical standards evolve. To categorize MRI images, several machine learning and deep learning approaches such as Support-Vector Machine (SVM), K-Nearest Neighbors (KNN), and Convolutional Neural Network (CNN) are being developed.

To increase the multiple classification accuracy of brain tumor MRI images, Srikanth and Venkata Suryanarayana (2021) developed a Deep Neural Network (DNN)-based VGG-16 (2014) network. As a result of the training, a 98% accuracy in producing results that were close to reality was achieved. Deepak and Ameer (2019) developed a method for categorizing three different forms of brain tumors. The transfer learning method was used to extract features from MRI images. The pre-trained GoogLeNet (2014) CNN network was used. For classification after the fully connected layer in the GoogLeNet network, the SVM and KNN classifiers were applied instead of the Softmax classifier. As a result of the experiments, 98% accuracy was obtained. Jia and Chen (2020) proposed the Fully Automatic Heterogeneous Segmentation (FAHS-SVM) approach for brain tumor detection and segmentation using SVM based on deep learning techniques. An extreme learning machine (ELM) method was used to categorize MRI images and extract features. The proposed method detected between healthy and unhealthy tissues with 98.51% accuracy.

Irmak (2021) presented three different CNN architectures for multi-classification in the early

diagnosis of brain cancer. To adjust the hyperparameters of the suggested CNN architectures, they were automatically calculated using the grid search optimization technique. The first proposed CNN model detected brain tumors with 99.33% accuracy. The second model had 92.66% accuracy in classifying brain cancers into five types: normal, glioma, meningioma, pituitary, and metastatic. In contrast, the third CNN model had 98.14% accuracy in classifying brain tumors as grade II, grade III, or grade IV.

MRI is used in the diagnosis of multiple sclerosis (MS) and brain tumors. Siar and Teshnehlab (2019) proposed a CNN for diagnosing brain tumors and MS simultaneously. The researchers used MRI images of 200 patients and healthy individuals. A total of 1286 images were used for training, and 384 images were used for testing. As a result of the training, they achieved a 96% accuracy rate in the diagnosis of MS and brain tumor patients. Hashemzahi et al. (2020) suggested a hybrid technique combining CNN and neural autoregressive distribution estimation (NADE). The most essential characteristic of this method is its ability to extract features and estimate data distribution rapidly and automatically. The approach examined 3064 CE-MRI images from 233 patients, including 1426 images of gliomas, 708 images of meningiomas, and 930 images of pituitary tumors. The proposed method was shown to have a classification accuracy of 95%.

Aziz et al. (2021) proposed an ensemble framework for brain tumor categorization. The CNN architecture was built using pre-trained ResNet-50 (2015) and Densenet-201 (2016) networks. These networks were retrained using transfer learning after they were updated. For the best feature selection, an efficient ant colony optimization (EACO) algorithm was proposed. The BRATS 2019 dataset was used in the experiments, and the classification accuracy was 87.7% for high-grade glioma (HGG) and 84.6% for low-grade glioma (LGG). Using a CNN's two-stage feature set, Aurna et al. (2022) suggested a new method for the exact and automatic categorization of brain tumors. An ensemble learning-based architecture was developed by merging the pre-trained VGG-19, EfficientB0 (2019), ResNet-50, Inception-V3 (2015), and Xception (2016) models and the proposed CNN model to find the best features in the proposed method. The best extracted features were chosen using the PCA algorithm. The proposed model was able to classify correctly with an accuracy of 99.13%. Noreen et al. (2021) developed an ensemble learning-based method to classify brain tumors. For feature extraction, the proposed method uses the pre-trained Inception-V3 and Xception models. The characteristics extracted from the CNN model outputs were categorized using a variety of machine-learning techniques, including softmax, random forest (RF), SVM, and K-NN, with 94% accuracy. Sajid et al. (2019) proposed a deep learning-based method for brain tumor

segmentation using MRI images. They used a patch-based hybrid CNN architecture for this. If the output label could not be predicted while analyzing the network output, labeling was performed using both local and contextual information. The images were normalized using a preprocessing step and then post-processed to reduce minor positive errors in the proposed method, thus skipping the CNN network feed-forward. The BRATS 2013 dataset was used to train the network, and sensitivity and specificity values of 0.86 were obtained according to the membrane score.

In this study, we proposed a novel CNN model for brain tumor multi-classification using brain MRI images. Three different state-of-the-art CNN models were used for the comparison: AlexNet, ShuffleNet, and SqueezeNet. According to the results obtained in the experimental studies, the proposed model outperformed other models.

This paper is organized as follows: section 2 presents material and method. Section 3 presents experimental results and section 4 presents discussions. in the section 5, results are given.

2. Material and Method

This section contains details of the proposed method and the dataset used. In addition, in this study, article research and publication ethics were complied with.

2.1. The Dataset

In this study, the dataset from Kaggle (2020) includes brain MRI images that are divided into four classes: meningioma, pituitary, glioma, and no tumor. This dataset contains 3264 images. Different numbers of images are included in each class. There are 500 images in the no tumor class, 937 images in the meningioma class, 901 images in the pituitary class, and 926 images in the glioma class. Table 1 lists the number of classes in the dataset and the number of images used for testing and training in each class. The dataset was split into training and testing datasets. Some examples of the training and test images are shown in Figure 1 and Figure 2.

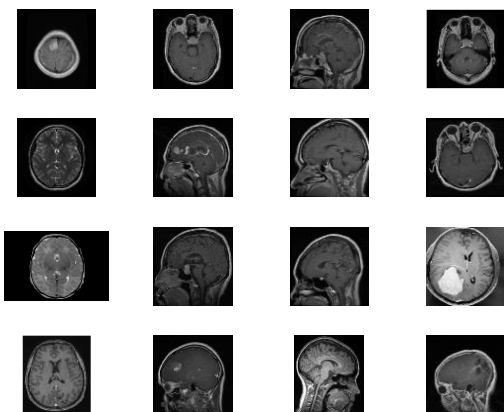


Figure 1. Train Images

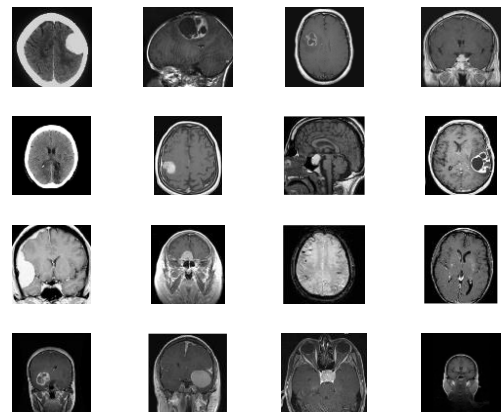


Figure 2. Test Images

Table 1

Classes in Data Set and the Number of Images Used for Training and Testing in Each Class.

Class	Train (80%)	Test (20%)	Total
Meningioma	750	187	937
Pituitary	721	180	901
Glioma	741	185	926
No Tumor	400	100	500
Total	2612	652	3264

2.2. Data Pre-preparation

In this study, several parameters were adjusted to obtain a unique CNN model. Among these parameters, the dataset must be resized to adjust the model input image size. For this purpose, the original dataset was transformed into different sizes in the flow diagram shown in Figure 3, and the best result was obtained with an input image size of 224×224×3.

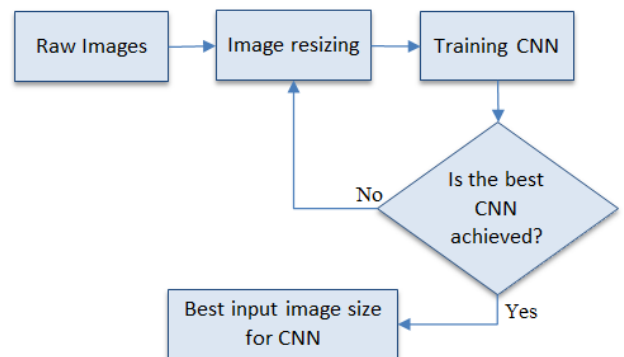


Figure 3. Flow Diagram Finding the Best Input Image Size

2.3. Proposed CNN Architecture

CNNs have been widely used in many other fields where the input data can be any signal, such as audio and video, despite the fact that they now focus on image classification and accept images as input data. Feature extraction and classification are the two components of a standard CNN model. The five primary layers of the CNN architecture are the input, convolution, pooling, fully connected, and classification layers. Through successive trainable layers arranged sequentially, the CNN conducts feature extraction and classification. Convolutional and pooling layers are often included in the feature extraction phase of a CNN, whereas fully connected and classification layers are typically included in the classification phase.

The architecture of the proposed method is shown in Figure 4. First, the images in the dataset were resized. Following the resizing procedure, the dataset was split into training (80%) and test (20%) sets. During the training process, more than one CNN model was designed and trained. The layer architecture of the CNN model that provides the highest accuracy rate among the models is shown in Figure 6. As seen in the figure, The CNN model has 24 layers that are 1 input, 7 convolutions, 7 ReLu, 3 batch normalization, 3 max pooling, 1 fully connected, 1 softmax and 1 classification layers. The parameter values for each layer of the model are listed in Table 2.

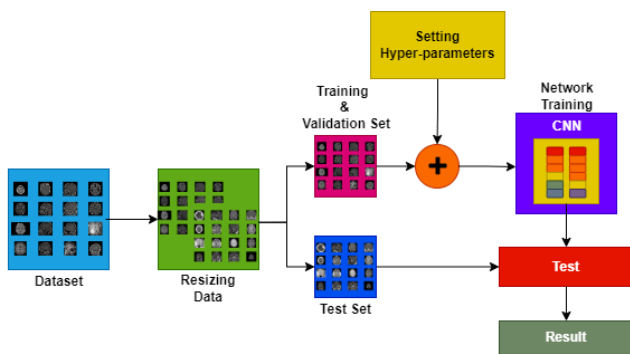


Figure 4. Flowchart of the Proposed Method

3. Experimental Studies

The technical details of the computer used for the experimental studies and the experimental results are presented in this section.

3.1. Technical Specification of the Computer

In the experimental tests, the deep learning library was implemented using the MATLAB 2021b software. The computer's technical specifications for use in experiments are as follows: Intel(R) Core (TM) i5-8400 CPU @ 2.80GHz (6 CPUs), 2.8GHz, 16 GB RAM, and NVIDIA GeForce GTX 1080 Ti with 11 GB memory.

3.2. Experimental Results

Three different pre-trained CNN models: AlexNet, ShuffleNet, and SqueezeNet, as well as the proposed CNN model, were used in the experiments. These pre-trained models were trained on millions of labeled data. Our model was trained only on the dataset used in this study. The hyperparameters are crucial for model training. Therefore, they should be carefully chosen. Table 3 lists the hyperparameters selected for this study. Optimizers such as SGD, Adam, Adagrad, AdaDelta, and RMSProp are algorithms or methods used to change the attributes of a neural network, such as weights and learning rate, to reduce losses. The learning rate controls the weight update in the optimization algorithm. It can use a fixed learning rate, gradually decreasing learning rate, momentum-based methods, or adaptive learning rates, depending on the choice of optimizer. The number of epochs is the number of times that the entire training set passes through the neural network. The batch size is typically preferable in the learning process of a CNN. A range of 16–128 is a good choice for testing. SGDM was selected as an optimizer because it showed better performance during the training phase than the other optimizers. The learning rate is usually chosen as 0.001 for classification problems. The accuracy of the models did not change after the 17th epoch. Therefore, 17 was selected to reduce the computational cost. The GPU memory of the computer confines the amount of data that will be processed simultaneously. Therefore, in this study, we used a batch size of 64. This value is the upper limit for GPU memory used in the study.

In the first experiment, AlexNet was used; however, the size of the image input layer was 227×227×3. To train the model, we replaced the image input layer with a 224x224x3 dimensional input. Additionally, AlexNet's fully connected layer includes 1000 classes. It has been replaced with a new fully connected layer with four classes. After 17 epochs, a classification accuracy of 80.5% and a loss of 0.47 are obtained in the training phase. It is seen in Figure 5. The confusion matrix obtained by AlexNet during the test process after the training phase is shown in Figure 10.

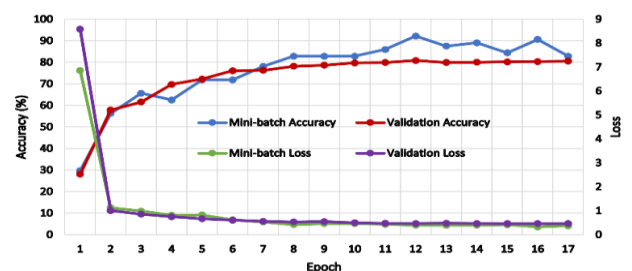


Figure 5. Accuracy and Loss Curves for AlexNet



Figure 6. Proposed CNN Model

Table 2

Classes in Data Set and the Number of Images Used for Training and Testing in Each Class

Layer Name	Activation Maps	Learnable Parameters	Total Learnable Parameters
Input	224x224x3	-	0
Conv2D-1	224x224x32	Weights:1x1x3x32, Bias:1x1x32	128
ReLU-1	224x224x32	-	0
Conv2D-2	224x224x64	Weights:1x1x32x64, Bias:1x1x64	2112
ReLU-2	224x224x64	-	0
MaxPool2D-1	111x111x64	-	0
BatchNorm-1	111x111x64	Offset: 1x1x64,	128
Conv2d-3	110x110x64	Scale: 1x1x64	16448
ReLU-3	110x110x64	Weights:2x2x64x64, Bias:1x1x64	0
Conv2D-4	108x108x64	-	36928
ReLU-4	108x108x64	Weights:3x3x64x64, Bias:1x1x64	0
Conv2d-5	106x106x128	-	73856
ReLU-5	106x106x128	Weights: 3x3x64x128, Bias:1x1x128	0
MaxPool2D-2	51x51x128	-	0
BatchNorm-2	51x51x128	-	256
Conv2D-6	49x49x128	Offset: 1x1x128,	147584
ReLU-6	49x49x128	Scale: 1x1x128	0
Conv2D-7	46x46x128	Weights: 3x3x128x128, Bias:1x1x128	262272
ReLU-7	46x46x128	-	0
MaxPool2D-3	9x9x128	Weights: 4x4x128x128, Bias:1x1x128	0
BatchNorm-3	9x9x128	-	256
FC	1x1x4	-	41476
Softmax	1x1x4	Offset: 1x1x128,	0
Classification Output	1x1x4	Scale: 1x1x128	0
Number of total learnable parameters			581444

Table 3

Hyperparameters

Parameters	Value
Optimizer	SGDM (stochastic gradient descent with momentum)
Learning Rate	0.001
Epoch	17
Batch Size	64

In the second experiment, ShuffleNet pre-trained model was used. The input size of the ShuffleNet was $224 \times 224 \times 3$. Similar to AlexNet, ShuffleNet's fully connected layer includes 1000 classes. It has been replaced with a new fully connected layer that also has four classes. The convergence graphs obtained using ShuffleNet are presented in Figure 7. ShuffleNet achieved a classification accuracy of 90.17% and loss of 0.28 after 17 epochs. The confusion matrix obtained by ShuffleNet for the test images is shown in Figure 11.

proposed CNN model on the test images is given in Figure 13.

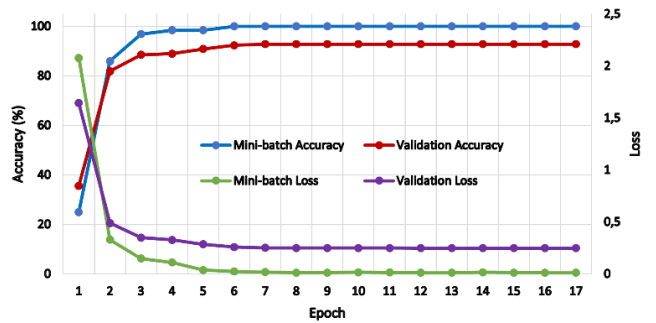
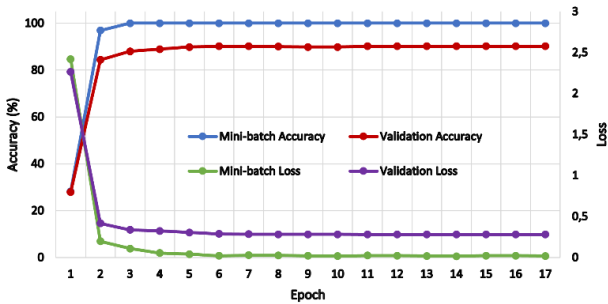


Figure 9. Accuracy and Loss Curves for Proposed CNN Model

Figure 7. Accuracy and Loss Curves for ShuffleNet

In the third experiment, SqueezeNet was used. However, the size of the image input layer of SqueezeNet was $227 \times 227 \times 3$. For training the model, we replaced the image input layer with a $224 \times 224 \times 3$ dimensional input. In addition, SqueezeNet's fully connected layer includes 1000 classes. It has been replaced with a new fully connected layer that has four classes. As shown in Figure 8, after 17 epochs, a classification accuracy of 89.95% and a loss of 0.34 are obtained after the training process. The confusion matrix obtained by SqueezeNet for the test images is shown in Figure 12.

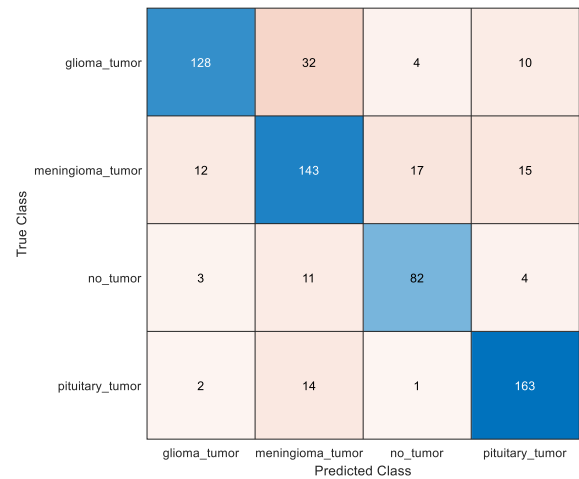


Figure 10. Confusion Matrix for AlexNet

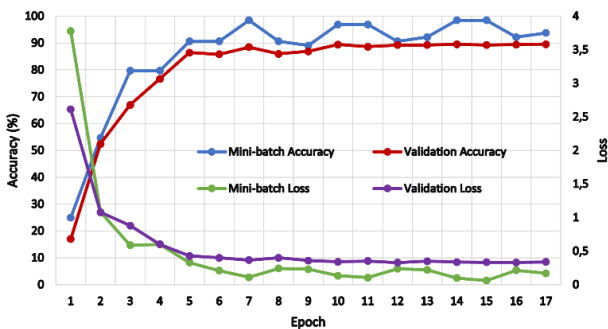


Figure 8. Accuracy and Loss Curves for SqueezeNet

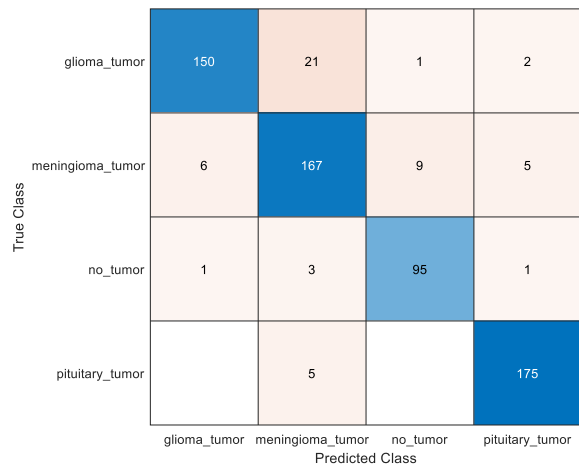


Figure 11. Confusion Matrix for ShuffleNet

Finally, experimental studies are conducted using the proposed CNN model. Convergence graphs of the proposed model are shown in Figure 9. After the 17th epoch, the accuracy rate was 92.82% and the loss value was 0.25. The confusion matrix obtained by the

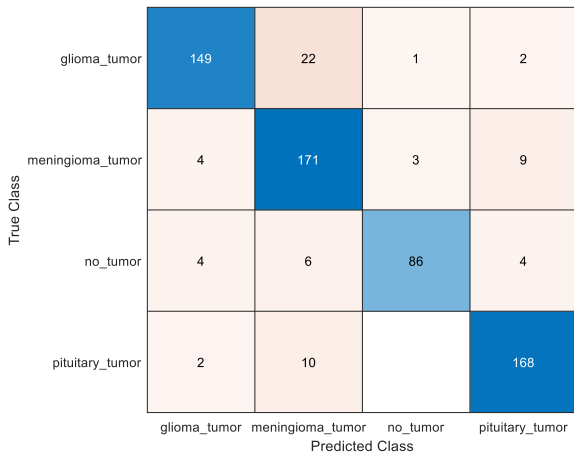


Figure 12. Confusion Matrix for SqueezeNet

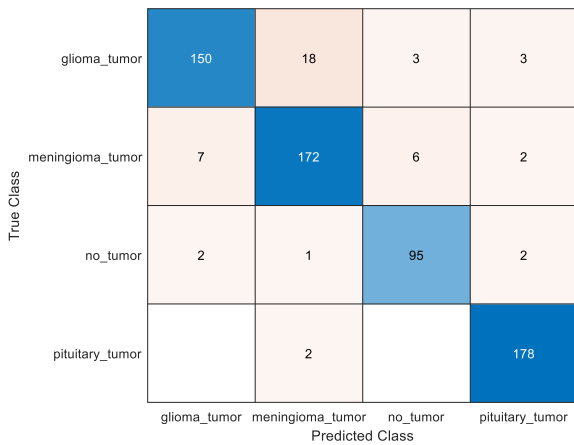


Figure 13. Confusion Matrix for Proposed CNN

The comparison between the proposed CNN model and other state-of-the-art models is presented in Table 4. Table 4 shows that the highest accuracy rate is obtained using the proposed CNN. The other models are ShuffleNet, SqueezeNet, and AlexNet in descending order.

Table 4
Comparison Validation Accuracy and Loss Values with the Other Studies

Model	Validation accuracy (%)	Loss
AlexNet	80.5	0.47
ShuffleNet	90.17	0.28
SqueezeNet	89.95	0.34
Proposed CNN	92.82	0.25

The accuracy values obtained using the models for the test data are listed in Table 5. In the table, the proposed

model achieved the highest accuracy rate with 92.82%, recall rate with 92.5%, precision rate with 93% and F1-score with 93%. The other models are ShuffleNet, SqueezeNet, and AlexNet in descending order.

Table 5
Comparison Performance Metrics with the Other Studies (%)

Model	Accuracy	Recall	Precision	F1-Score
AlexNet	80.19	80.5	80.5	80.25
ShuffleNet	91.58	91.75	91.75	91.75
SqueezeNet	89.55	91	89	89.75
Proposed CNN	92.82	92.5	93	93

4. Discussion

It is known that CNN-based methods used in the early diagnosis of brain tumors are widely used. However, studies are still being conducted to determine the model with the best performance among these methods. The biggest difference between these studies is in the parameter values used in the design of the models. Therefore, researchers are developing CNN-based architectures with different parameters for tumor classification in brain MRI images. In this study, a CNN model was designed to classify brain tumors using brain MRI. To show the efficiency of our model, we compared it with 3 different pre-trained CNN models.

The confusion matrix for AlexNet is shown in Fig .10. It is obvious that no_tumor class is the best estimated class with 82 correct and 40 incorrect estimations. meningioma_tumor class is the worst estimated class with 143 correct and 101 incorrect estimations. Confusion matrix in Figure 11 shows ShuffleNet's estimation performance. pituitary_tumor class is the best estimated class with 175 correct and 13 incorrect estimations. meningioma_tumor class is the worst estimated class with 167 correct and 52 incorrect estimations. For SqueezeNet in Fig 12, the no_tumor class is the best estimated class, with 171 correct and 54 incorrect estimations. Meningioma_tumor class is the worst estimated class with 167 correct and 52 incorrect estimations.

The confusion matrix in Figure 13 shows the estimation performance of the proposed model. The pituitary_tumor class is the best estimated class, with 178 correct and nine incorrect estimations. The no_tumor class has 95 correct estimations and 14 incorrect estimations. Glioma_tumor has 150 correct and 33 incorrect estimations, respectively. Finally, the worst estimated class for proposed model is meningioma_tumor class with 172 correct and 36 incorrect estimations.

It was observed that the proposed CNN model performed better than the other models. These performance values were achieved without pretraining. Other pre-trained models performed poorly despite being used with thousands of data. This indicates that better models can be designed without transfer learning on fewer datasets.

5. Conclusions

Brain tumors are among the most harmful anomalies to human health. Precisely classifying brain tumors is difficult and relies on the experience of doctors and experts. With the advancement of computer science, computers have begun to implement classification issues using machine learning and deep learning approaches. In this study we proposed a CNN model to classify brain tumors using brain MRI images. In the proposed model there are 24 weighted layers that was explained in section 2.

The experiments were conducted on a dataset of four classes. To demonstrate the efficiency of the proposed CNN model, it was compared with three pre-trained CNN models: AlexNet, ShuffleNet, and SqueezeNet. In comparison, the proposed CNN model had the highest classification accuracy of 92.82% and the lowest loss of 0.2481. ShuffleNet has the second highest classification accuracy of 90.17% and a loss of 0.28. SqueezeNet has higher classification accuracy than AlexNet. AlexNet has the worst accuracy and loss values.

In the next studies, we are planning to merge a couple of pre-trained models to increase classification accuracy on MRI images.

Author Contribution Statements

The first author (Muhammed CELIK) is responsible for data curation, writing- original draft, software, investigation, visualization, and resources. The second author (Ozkan INIK) is responsible for supervision, conceptualization, validation, methodology, formal analysis, writing- reviewing and editing.

Conflict of Interest

The authors (Muhammed CELIK and Ozkan INIK) have no conflicts of interest to disclose. This study complies with scientific research and publication ethics and principles.

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THE EFFECT OF THE THERMOMECHANICAL PROCESSING ON THE MICROSTRUCTURE AND HARDNESS OF $(\text{Co}_{25}\text{Cr}_{15}\text{Fe}_{20}\text{Ni}_{40})_{83}\text{Al}_{17}$ HIGH ENTROPY ALLOY

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Keywords

Eutectic High Entropy Alloy
Vacuum Arc Melting
Rolling
Annealing

Abstract

$(\text{Co}_{25}\text{Cr}_{15}\text{Fe}_{20}\text{Ni}_{40})_{83}\text{Al}_{17}$ is a eutectic high entropy alloy (EHEA), which is composed of face centered cubic (FCC) and body centered cubic (BCC) phases. This dual (FCC+BCC) phase mixture provides good ductility and strength combination. In the scope of this study, it was aimed to analyze the effects of mechanical, thermal and thermomechanical processes on the microstructure and hardness of $(\text{Co}_{25}\text{Cr}_{15}\text{Fe}_{20}\text{Ni}_{40})_{83}\text{Al}_{17}$ EHEA, which was produced by the vacuum arc melting and casting method. With this aim, cold and hot rolling as well as different annealing treatments were applied to the as-cast plates. The cold-rolling was performed at room temperature while the hot rolling temperature was varied in between 500-1100 °C. The maximum deformation that can be applied was 50% and 60 % after cold and hot rolling, respectively. Since the results of Rietveld analyses suggested that FCC content increases with increasing deformation temperature, the limited deformability was attributed to the deformation-induced ordering and/or local amorphization within FCC phase. The hardness was increased from 280 HV to 412 HV after 50% cold-rolling. A similar high hardness value (399 HV) was obtained after ~50% deformation at 750 °C, indicating that the dynamic recrystallization had no significant effect up to 1100 °C.

TERMOMEKANİK İŞLEMİN $(\text{Co}_{25}\text{Cr}_{15}\text{Fe}_{20}\text{Ni}_{40})_{83}\text{Al}_{17}$ YÜKSEK ENTROPİLİ ALAŞIMININ MİKROYAPISINA VE SERTLİĞİNE ETKİSİ

Anahtar Kelimeler

Ötektik Yüksek Entropili Alaşım
Vakum Ark Ergitme
Haddeleme
Tavlama

Öz

$(\text{Co}_{25}\text{Cr}_{15}\text{Fe}_{20}\text{Ni}_{40})_{83}\text{Al}_{17}$ yüzey merkezli kübik (FCC) ve hacim merkezli kübik (BCC) fazlardan oluşan bir ötektik yüksek entropili alaşımdır (EHEA). Bu ikili faz karışımı (FCC+BCC), iyi süneklik ve mukavemet kombinasyonu sağlar. Bu çalışma kapsamında, vakum ark ergitme ve döküm yöntemi ile üretilen $(\text{Co}_{25}\text{Cr}_{15}\text{Fe}_{20}\text{Ni}_{40})_{83}\text{Al}_{17}$ EHEA'nın mikroyapısı ve sertliği üzerine mekanik, termal ve termomekanik süreçlerin etkisinin incelenmesi amaçlanmıştır. Bu amaçla, döküm levhalara soğuk ve sıcak haddeleme ile farklı tavlama işlemleri uygulanmıştır. Soğuk haddeleme oda sıcaklığında yapılırken, sıcak haddeleme sıcaklığı 500-1100 °C arasında değiştirilmiştir. Soğuk ve sıcak haddeleme sonrasında uygulanabilen maksimum deformasyon sırasıyla %50 ve %60 olmuştur. Rietveld analizlerinin sonuçları, FCC miktarının artan deformasyon sıcaklığı ile arttığını gösterdiğinden, sınırlı deforme edilebilirlik, FCC fazında deformasyona bağlı düzenlenime ve/veya lokal amorfizasyona bağlanmıştır. %50 soğuk haddelemeden sonra sertlik 280 HV'den 412 HV'ye yükselmiştir. Benzer yüksek sertlik değeri (399 HV) 750 °C'de ~%50 deformasyondan sonra elde edilmiştir ki bu da dinamik yeniden kristalleşmenin 1100 °C'ye kadar belirgin bir etkisinin olmadığını göstermektedir.

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1. Introduction

(Co₂₅Cr₁₅Fe₂₀Ni₄₀)₈₃Al₁₇ is an eutectic high entropy alloy (EHEA), which is composed of face centered cubic (FCC) and body centered cubic (BCC) phases. This dual (FCC+BCC) phase mixture provides good ductility and strength combination (Yiping et al., 2014). In the scope of this study, the effects of cold and hot rolling as well as annealing on the microstructure and hardness of (Co₂₅Cr₁₅Fe₂₀Ni₄₀)₈₃Al₁₇ alloy were investigated.

2. Literature Review

High entropy alloy (HEA) concept is a highly appealing topic for industry in recent years. This new design of alloying has successful outcomes in various fields considering their mechanical and physical properties, such as the unique wear resistance, excellent strength and thermal stability at elevated temperatures, superior elongation, great fatigue and fracture resistance (Tong et al., 2005; Senkov, Wilks, Scott and Miracle, 2011; Hemphill et al., 2012; Pickering and Jones, 2016).

The strength originated from BCC phase and the ductility originated from FCC phase were combined and optimized with eutectic high entropy concept (Yiping et al., 2014). Further improvements can be achieved by thermomechanical processing of EHEAs. Although there are limited studies in the literature, a brief review will be presented.

Bhattacharjee et al. (2018) studied the effects of cryo-rolling and annealing on the microstructure and mechanical properties of AlCoCrFeNi_{2.1} EHEA. After multi-pass cryo-rolling, reduction in thickness up to 90% was achieved. The high-strength that was achieved after cryo-rolling resulted in brittleness of the alloy but after annealing at 800 °C for 1 hour, the alloy displayed a good combination of strength and ductility. In a similar study, Wani et al. (2017) studied the effect of cold-rolling and annealing on the microstructure and mechanical properties of AlCoCrFeNi_{2.1} EHEA. They revealed that 90% cold-deformation has resulted in disordering of L₁₂ phase while annealing resulted in the breakdown of lamellar eutectic microstructure. The warm-rolling of the same alloy was studied by Reddy et al. (2019) at different temperatures (400 °C, 600 °C and 750 °C). The deformation induced disordering of L₁₂ phase was also detected after 90% deformation at 750 °C. Moreover, the fraction of FCC/L₁₂ phase has decreased while nonlamellar structure became more dominant after deformation at 750 °C. High temperature deformation characteristics, on the other hand, was studied by Tian et al. (2020) for AlCoCrFeNi HEA. It was observed that the equiaxed dendritic microstructure after casting became elongated normal to the compressive direction while grain elongation extent increased with the increased strain rate. Moreover, σ and FCC phases in addition to A₂+B₂ structure of the as-cast alloy were detected after hot-deformation.

In a recent study, the effect of the interface coherency between FCC/BCC layers on the plastic deformation characteristics was investigated (Yang et al., 2023). It was shown that the coherency of the interphase has a crucial role in the plastic deformation mechanisms of EHEAs. If the interface between FCC and BCC phases is coherent, then co-deformation takes place by continuous slipping of dislocations while semi-coherent interface is an effective barrier to dislocation penetration from FCC to BCC and results in local deformation of FCC. Moreover, the deformation-induced amorphization was detected under high-plastic deformation in the case of semi-coherent interface, which results in a considerable strengthening effect.

Although there are researches on the deformation of EHEAs other than AlCoCrFeNi system (Li, Yiping, Wei, Zhiqiang and Tingju, 2016; Jain, Rahul, Samal, Kumar and Phanikumar, 2020; Shah, Rahul, Bysahk, and Panikumar, 2021) detailed studies on the mechanisms are concentrated on AlCoCrFeNi systems (Li et al., 2021). In the scope of this study, a more complex alloy composition has been selected in order to contribute to the literature in terms of deformation characteristics of EHEAs, which is a recently developing research field.

3. Material and Methods

The phase diagram of (Co₂₅Cr₁₅Fe₂₀Ni₄₀)_{100-x}Al_x, which was calculated by ThermoCalc (2017) TCHEA2 database, is given in Figure 1. The composition of the alloy was selected to be (Co₂₅Cr₁₅Fe₂₀Ni₄₀)₈₃Al₁₇ in order to get a eutectic system since the studies on the deformation of eutectic HEAs (EHEAs) are still limited in literature. In this study, research and publication ethics were complied with.

Al, Co, Cr, Fe and Ni with at least 99.9 % purity (Alfa Aesar, USA) were vacuum arc melted and casted under argon atmosphere. In order to get homogenous structure, remelting were done for three times. The thickness of each casted plate was 6.6 mm while the width and length were 11.5 mm and 65 mm, respectively.

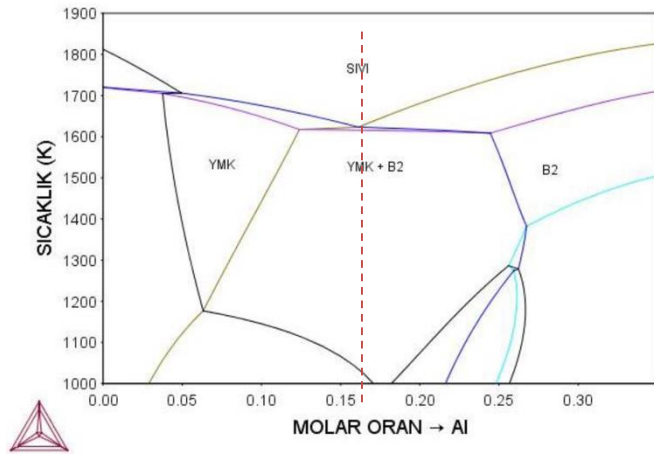


Figure 1. The Phase Diagram Of $(Co_{25}Cr_{15}Fe_{20}Ni_{40})_{100-x}Al_x$

$(Co_{25}Cr_{15}Fe_{20}Ni_{40})_{83}Al_{17}$ EHEA plates were either rolled at room temperature and annealed afterwards or hot rolling was applied to observe the effect of dynamic recrystallization. The rolling has continued up to maximum deformation that can be attained at that temperature. Lab-scale roll-mill (Durstion FSM160, England) was used for the deformation and the amount of deformation was calculated in terms of true strain using the reduction in the cross-sectional area of the plates. The annealing time after cold-rolling was kept constant at 1 hour. The maximum hot-rolling temperature, on the other hand, was selected to be 1100 °C since the melting temperature of the alloy is 1376 °C. All mechanical, thermal and thermomechanical processes were given in Table 1.

Table 1. All Processes That Were Applied on $(Co_{25}Cr_{15}Fe_{20}Ni_{40})_{83}Al_{17}$ EHEA Plates.

Treatment	Details
Cold Rolling	%50 Deformed
Annealing	%50 Deformed+ Annealed at 750 °C
	%50 Deformed+ Annealed at 1000 °C
Hot Rolling	%44 Deformed at 500 °C
	%53 Deformed at 750 °C
	%60 Deformed at 1100 °C

The metallographic specimen preparation was done with Struers automatic polishing machine and 25 vol. % nitric acidic solution (25 vol. % nitric acid + 75 vol. % distilled water) was used as etchant. All optical micrographs were taken at 200x magnification. Moreover, SEM (Zeiss, Supra 50VP, Oberkochen,

Germany) with an energy-dispersive X-ray spectroscopy (EDX) attachment was employed for detailed microstructural characterization. SEM micrographs were taken with back-scattered electron (BSE) mode under 20 kV excitation voltage.

XRD analyses (MiniFlex600, Rigaku, Japan) were applied with Cu-K α radiation at 40 kV and 15 mA and the scanning rate was 2°/min in between 30-90°. XRD analysis results of all plates were processed with Rietveld analysis to observe the change of the percentages of phases present.

The hardness measurements were done at the end of each process by using EMCO Test (Prüfmaschinen GmbH, Austria). Vickers micro-hardness measurements were taken under 10 kg force that is applied for 3 seconds and at least 5 measurements were taken to determine average micro-hardness values.

4. Results and Discussions

The microstructures of all alloys were generally consisted of lamellar eutectic structure as given in Figure 2. A line analysis (yellow line on Figure 2 (a)) was taken to determine the phases that constitutes the eutectic phase mixture. The phase having lighter color (seems to have higher level) was labelled as region A while the other one having darker color (seems to have lower level) was labelled as region B. The amounts of Al and Ni were observed to be increased in region B while the amounts of other elements were observed to be increased in region A as the result of EDX analysis (Figure 2(b)). Accordingly, lamellar structure was found to be consisted of FCC/L12 (region A) and BCC/B2 (region B) phases.

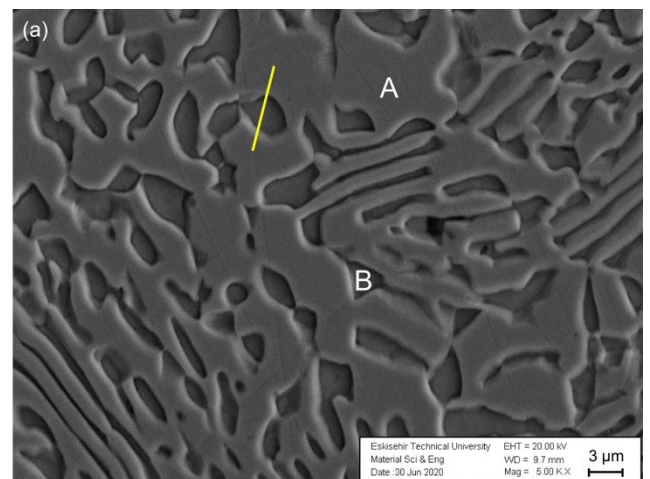


Figure 2. (a) SEM Micrograph (5000X) Showing Where EDX Line Analysis Was Taken.

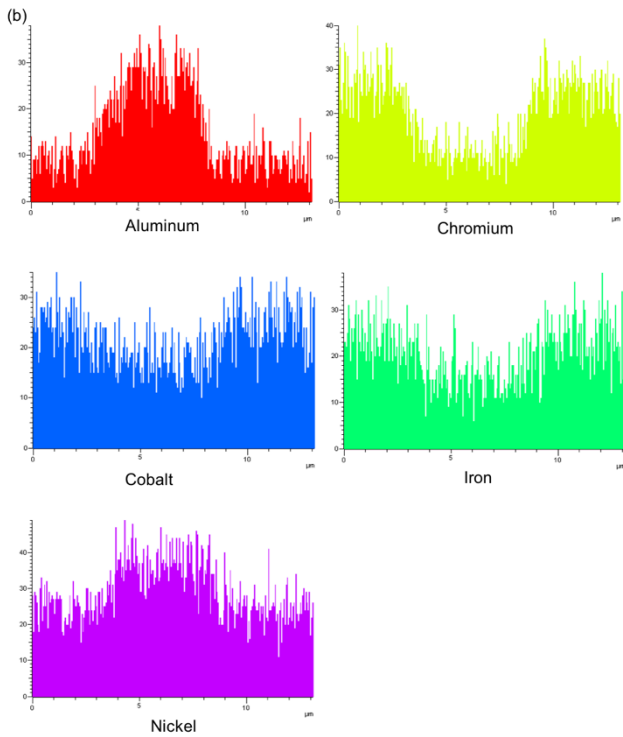


Figure 2. (b) The Results Of EDX Line Analysis, Where Red Belongs To Aluminum, Yellow Belongs To Chromium, Green Belongs To Iron, Blue Belongs To Cobalt And Pink Belongs To Nickel.

As it can be seen from Figure 3, the exact grain boundaries could not be distinguished, rather domain structures were detected in the microstructure of $(Co_{25}Cr_{15}Fe_{20}Ni_{40})_{83}Al_{17}$ alloys.



Figure 3. The Optical Micrograph Of As-Cast Alloy.

The microstructure of cold-rolled alloy was given in Figure 4. The refinement of the microstructure after cold-rolling is obvious in the optical micrograph. The black points in SEM micrograph, on the other hand, belong to casting porosities.

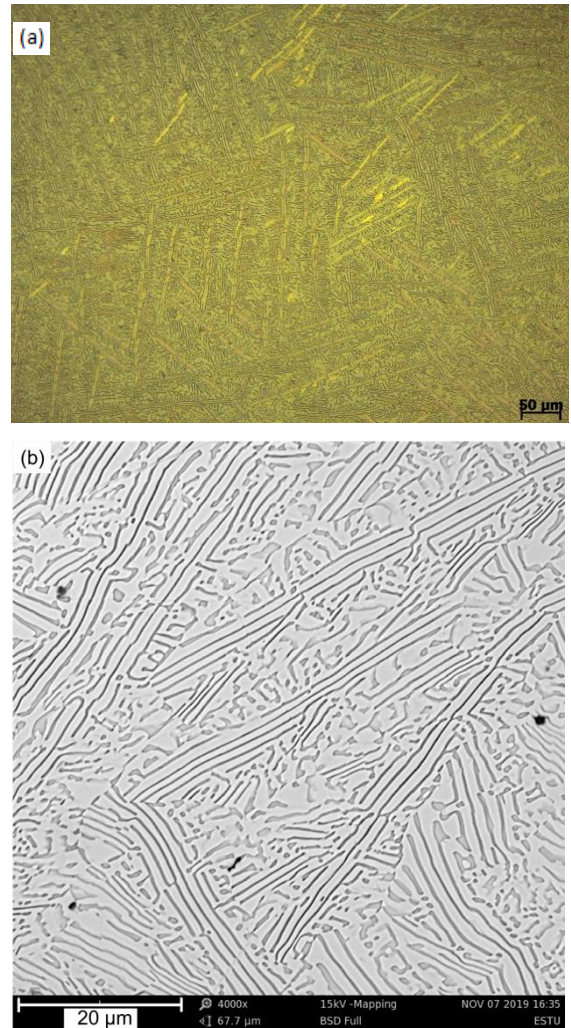


Figure 4. (a) Optical And (b) SEM Micrographs Of 50% Cold-Rolled Alloy (4000X).

The cold-rolled plates were annealed at 750 °C and 1000 °C, respectively (Figure 5). The lamellar structure was maintained after annealing. However, the edges of the lamellae were observed to change from planar to a more roughed structure.

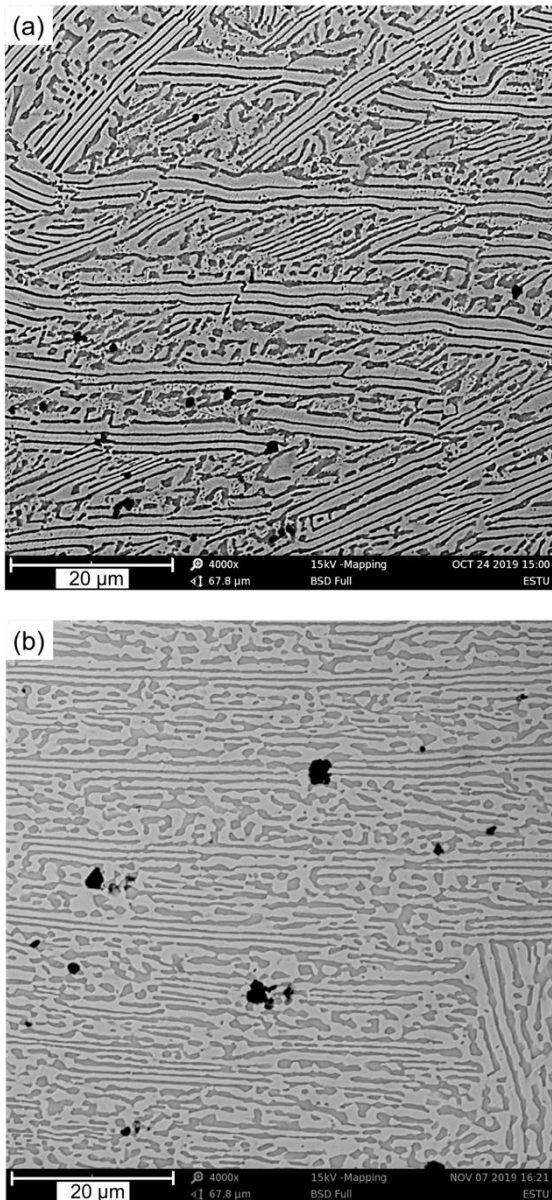


Figure 5. SEM Micrographs Of The Alloys, Which Were Annealed At (a) 750°C And (b) 1000°C, Respectively (4000X).

According to XRD analysis results, B2 peak was appeared at $\sim 35^\circ$ with the applied cold-rolling indicating a tendency towards ordering with deformation (Figure 6). Since ordered phases have lower deformability than disordered phases, this can be the reason of limited (maximum 50%) deformability during cold rolling. The peaks at $\sim 45^\circ$ and $\sim 85^\circ$, on the other hand, have become more diffuse. This was attributed to increased dislocation density with the applied deformation.

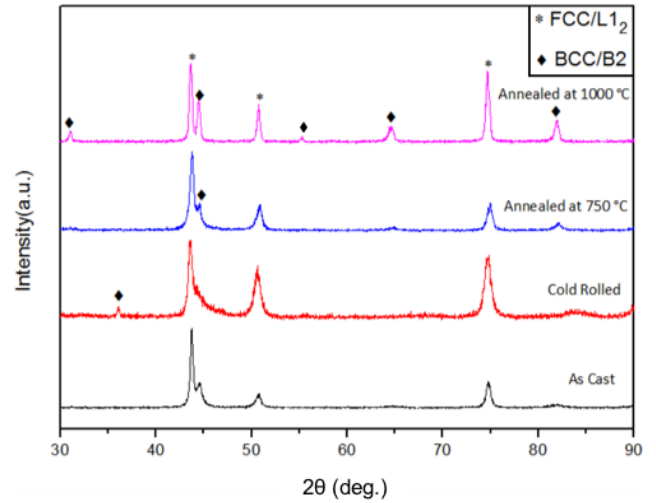


Figure 6. XRD Results Of As-Cast, Cold Rolled And Annealed Plates.

The Rietveld analyses (Table 2), on the other hand, indicated a slight decrease in FCC content after annealing.

Table 2. The Results Of Rietveld Analyses

Treatment	FCC / L1 ₂ (%)	BCC / B2 (%)
50% cold-rolled	70	30
Annealed at 750 °C	65	35
Annealed at 1000 °C	66	34
44% hot-rolled at 500 °C	68	32
53% hot-rolled at 750 °C	71	29
60% hot-rolled at 1100 °C	81	19

The microstructures after hot rolling at 500°C, 750°C, and 1100 °C were given in Figure 7. It was observed that the lamellar structure had become distorted with decreasing deformation temperature. Moreover, lamellae thicknesses were decreased with the increasing deformation temperature.

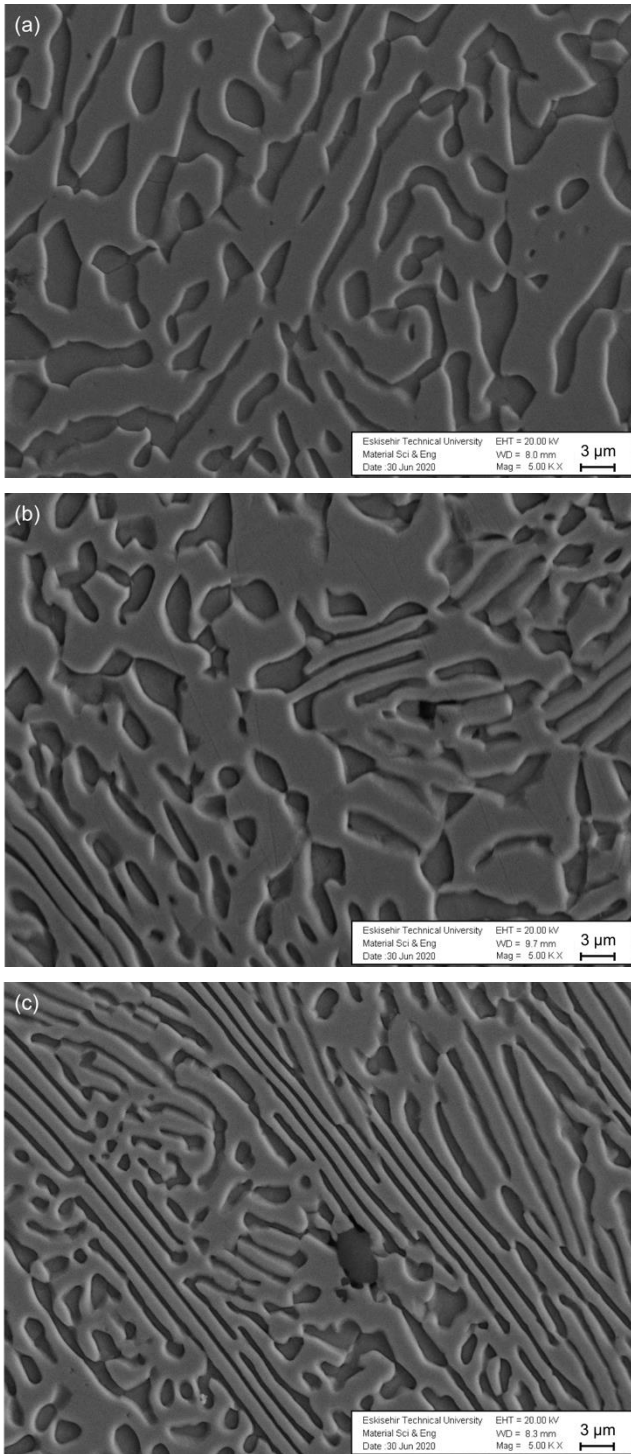


Figure 7. SEM Micrographs (5000X) Of The Alloys, Which Were Hot-Rolled At (a) 500 °C, (b) 750 °C And (c) 1100 °C, Respectively.

The results of XRD analyses after hot-rolling at various temperatures were given in Figure 8. The results obtained after hot-rolling at 500 °C were similar to that obtained after cold-rolling in terms of peak widening. This was attributed to the suppression of recrystallization due to the lower temperature of

deformation. The fraction of BCC/B2 phase was observed to be decreasing with increasing deformation temperature according to the Rietveld analyses. The maximum deformability has increased with the increased temperature, as expected.

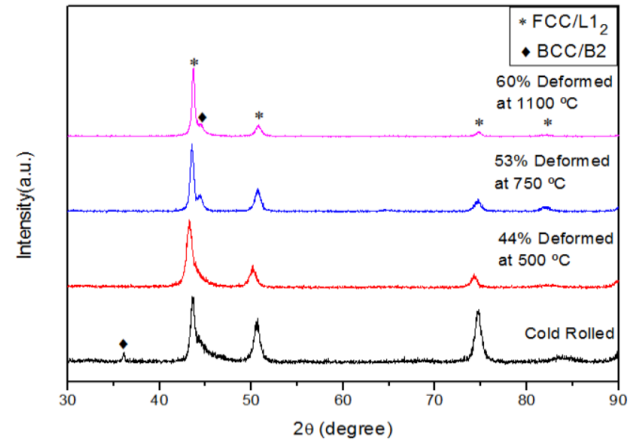


Figure 8. XRD Analyses Results Of Hot Rolled Plates (XRD Analysis Result of Cold Rolled Plate Was Added For Comparison).

The maximum deformation of 60% was attained after hot-rolling at 1100 °C. Although the FCC content of the alloy has increased with increasing deformation temperature (Table 2), the expected increase in deformability was not attained.

It was known that stacking fault energy (SFE) plays an important role in the deformation of FCC-based HEAs, especially when it is low (Su, Wu, Raabe and Li, 2019; Li, Zhao, Ritchie and Meyers, 2019; Paul, Tripathy, Saha and Bhattacharjee, 2023). Xu et al. (2021), on the other hand, revealed that SFE increases with increasing Al content while Deng et al. (2015) proposed increased Ni content also increases SFE. Since both Al and Ni contents of $(Co_{25}Cr_{15}Fe_{20}Ni_{40})_{83}Al_{17}$ is high, the effect of SFE was considered to be negligible on decreased deformability. Moreover, the deformation of dual-phase alloys commonly involves complex mechanisms and it was mentioned before that the nature of the interphase has a pronounced contribution (Yang et al., 2023). On the other hand, the formation of L_{12} nano-precipitates within FCC phase during low temperature annealing after cold-working has been reported (Gwalani et al., 2019). Accordingly, the deformation-induced ordering and/or amorphization can be the reasoning the behind the limited deformability.

Table 3. The Hardness of $(\text{Co}_{25}\text{Cr}_{15}\text{Fe}_{20}\text{Ni}_{40})_{83}\text{Al}_{17}$ EHEA Plates

Treatment	Hardness (HV)
As-cast	280 ±12
50% cold-rolled	412 ±7
Annealed at 750 °C	356 ±5
Annealed at 1000 °C	373 ±5
44% hot-rolled at 500 °C	393 ±8
53% hot-rolled at 750 °C	399 ±9
60% hot-rolled at 1100 °C	353 ±5

Table 3 shows the hardness values of the plates. The hardness was increased from 280 HV to 412 HV after cold-rolling as expected. The increase in hardness can both be attributed to increased dislocation density and stress-induced ordering. When the plates were annealed after cold-rolling, a decrease in hardness was observed but the hardness values were still higher with respect to that of as-cast plate. This can be due to the refinement of the structure as well as ordering of FCC phase, which cannot be detected with the available analysis methods.

The highest hardness among hot-rolled plates was measured after hot-rolling at 750°C. It was even higher when compared with the hardness of the plate, which was annealed at 750°C after cold-rolling, although having higher FCC content. This can be due to the balance between the generation of dislocations and the dynamic recrystallization. However, the ordering could also play a role in higher hardness. The presence of L1₂ phase can result in unusual variation of mechanical properties with temperature such as yield strength anomaly (Vikram et al., 2022). Transmission electron microscopy (TEM) analyzes to be performed at varying temperatures and/or under deformation can be enlightening about the origin of the results obtained.

5. Conclusions

In the scope of this study, the effects of cold and hot rolling as well as annealing on the microstructure and hardness of $(\text{Co}_{25}\text{Cr}_{15}\text{Fe}_{20}\text{Ni}_{40})_{83}\text{Al}_{17}$, which is a eutectic alloy, were investigated. It was chosen according to the relatively higher FCC content since FCC phase has higher ductility.

However, the maximum deformation of only 60% was attained after rolling at 1100 °C. Since the results of

Rietveld analyses suggested that FCC content increases with increasing deformation temperature, the limited deformability was attributed to the deformation-induced ordering and/or local amorphization within FCC phase. Further studies, especially with TEM, have to be conducted in order to be certain about the origin of this phenomenon.

Although, the maximum deformation could not exceed 60%, the hardness values indicate the strengthening of $(\text{Co}_{25}\text{Cr}_{15}\text{Fe}_{20}\text{Ni}_{40})_{83}\text{Al}_{17}$ HEAs up to ~50% with thermomechanical treatment. Moreover, the information that has gained during this study, has given insight to the behavior of eutectic HEAs under mechanical and/or thermal processes.

Araştırmacıların Katkısı

Bu araştırmada; H.B. Kocabaş, bilimsel yayın araştırması, makalenin oluşturulması, haddeleme ve karakterizasyon çalışmalarında; A. Özcan, alaşımın üretimi ve Rietveld analizlerinde ; H. Gaşan ve G.İ. Selimoğlu sonuçların yorumlanması ve makalenin oluşturulması konularında katkı sağlamışlardır.

Çıkar Çatışması

Yazarlar tarafından herhangi bir çıkar çatışması beyan edilmemiştir.

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THE BEHAVIOUR OF TWISTED TALL BUILDING STRUCTURES UNDER LATERAL LOADS

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Anahtar Kelimeler	Öz
Twisted tall building, seismic performance, wind loads, composite shear wall, case study	<i>Twisted tall building structures have recently been used as an architectural and structural form. On the other hand, there are very few studies on the behavior of twisted tall buildings under seismic and wind lateral loads. In this study, the behavior of twisted tall buildings under seismic and wind-induced loads is investigated and compared with their prismatic counterpart. As a case study, a twisted building in Miami, Florida, is modified by twisting all floor levels with an angle of 3 degrees. Lateral forces (wind and seismic) are considered for this location and using ASCE 7-16. The 3-dimensional models are created by using ETABS for analysis. The structural system of the building consists of a composite core system. The floor system consists of a post-tensioned concrete slab and the surrounding twisted columns are reinforced concrete. For the analysis of twisted tall building structures under lateral loads such as wind loads and seismic loads, the application of provisions and the behavior of prismatic and twisted tall building structures are discussed. In the study, it was found that the lateral stiffness of the twisted tall building under seismic loads is lower than that of the prismatic tall building.</i>

BURGULU YÜKSEK YAPILARIN YANAL YÜKLER ALTINDA DAVRANIŞI

Keywords	Abstract
Burgulu yüksek yapılar, deprem performansı, rüzgar yükleri, kompozit perde duvar, vaka analizi	<i>Burgulu yüksek bina yapıları son dönemlerde mimari ve yapısal bir form olarak kullanılmaktadır. Öte yandan, burgulu yüksek yapıların, deprem ve rüzgar yükleri altında yanall yükler olarak davranışına ilişkin çok az çalışma bulunmaktadır. Bu çalışmada, burgulu yüksek katlı yapıların deprem ve rüzgar yükleri altındaki davranışı incelenmiş ve emsali olan prizmatik yapı ile karşılaştırılmıştır. Bir vaka analizi olarak, Miami, Florida'da bulunan burgulu bir yüksek bina, tüm katları 3 derecelik bir açıyla döndürülerek düzenlenmiştir. Binanın bulunduğu konumdaki yanall kuvvetler (rüzgar ve sismik) dikkate alınmış ve ASCE 7-16 yönetmeliği kullanılmıştır. ETABS kullanılarak analiz için 3 boyutlu modeller oluşturulmuştur. Bina taşıyıcı sistemi, betonarme kolonlu kompozit bir çekirdekten oluşmaktadır. Döşeme sistemi ardgermeli betonarme döşemeye sahiptir ve burgulu kolonlar betonarmedir. Rüzgar yükleri ve sismik yükler gibi yanall yükler altında burgulu yüksek bina yapılarının analizi için, yönetmelik hükümlerinin uygulanması ve prizmatik, burgulu yüksek bina yapılarının davranışı kıyaslamalı olarak tartışılmıştır. Çalışmada, deprem yükleri altında burgulu yüksek binanın yanall rijitliğinin prizmatik yüksek binaya göre daha düşük olduğu tespit edilmiştir.</i>

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1. Introduction

Interest in tall buildings has continued from the past to the present. The construction of tall buildings has accelerated for reasons such as population growth, the

increased value of land in cities, prestige, and competition between countries. There are many building forms used to construct tall buildings, and one of these building forms is twisted tall buildings. Twisted tall buildings are defined by the Council on Tall



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Buildings and Urban Habitat (CTBUH) as the gradual rotation of the floor or facade toward the upper floors of the building. The popularity of twisted tall building structures is increasing day by day because twisted tall buildings have better aerodynamic performance under wind loads than prismatic structures (Günel and İlgin, 2014). The first example of a twisted tall building is the 190-meter Turning Torso in Malmö, Sweden, which was completed in 2005. The twisted 632-meter Shanghai Tower is currently the world's second tallest building.

Some researchers have published on the topic of twisted tall building structures. In (Moon, 2012, 2015), maximum displacement and lateral stiffness by modeling the twisted structure at different angles and heights and found that the lateral stiffness decreases with increasing rotation in twisted structures. It was stated that the twisted tall building structures are not very beneficial to the structural system. In (Kim and Hong, 2011), the tilted structure with a braced core and the twisted structure with a reinforced concrete core with the prismatic structure compared and evaluated the capacities of progressive collapse resistance with dynamic analysis. It was observed that the potential progressive collapse of the twisted structure did not change significantly compared to the prismatic structure. In (Lee, Kim, Kang and Kim, 2014), seismic behavior of a 60-story twisted tall building with an outrigger system at different angles and locations was investigated. It was found that the angle of rotation affects the relationship between bearing capacity and story displacements for twisted tall buildings. In (Kwon and Kim, 2014), resistance to earthquake loads by removing columns in twisted structures with different angles was investigated. Several researchers have conducted experimental studies on twisted tall buildings with wind tunnel tests (Tanaka et. al., 2013 and Bilgen, 2019). In these studies, twisted tall building structures were found to perform well in terms of aerodynamic shape. In (Shabab, Irtaza and Agarwal, 2021), the aerodynamic coefficients of prismatic and twisted tall buildings with different cross-sections were compared using the computational fluid dynamics method. It was found that wind aerodynamic load is lower in twisted tall buildings than in prismatic tall buildings.

Some researchers have made some classifications of twisted tall buildings (Vollers, 2015 and Taşkın, 2019). In this study, twisted tall building structures are divided into two types in terms of structural engineering. The first type (Type-1) is twisted structures in which the center of the structural system is fixed in the core and the facades or floors rotate. The second type (Type-2) is twisted structures in which the outer structural system rotates while the inner core is fixed. Examples of Type-1 and Type-2 are shown in Fig.1 and Fig.2.



(a) (b)

Figure 1. Examples of Type-1 Model of Twisted Tall Building Structures: (a) Evolution Tower, Russia (b) Shanghai Tower, China



(a) (b)

Figure 2. Examples of Type-2 Model of Twisted Tall Building Structures: (a) Cayan Tower, United Arab Emirates ; (b) Al Bidda Tower, Qatar

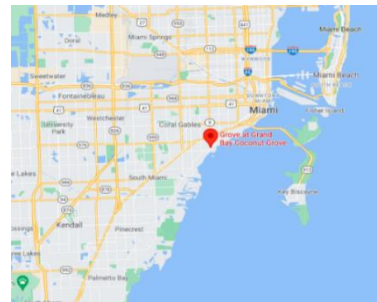


Figure 3. Location of Investigated Twisted Tall Building Structures

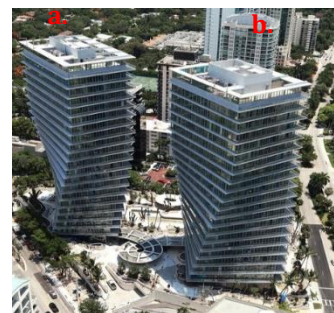


Figure 4. Grove at Grand Bay Towers a. Grove at Grand Bay North Tower b. Grove at Grand Bay South Tower

Grove at Grand Bays is the first twisted tall building in the United States of America. Grove at Grand Bays consists of two buildings, North and South, and they have high ceilings and large terraces. In this study, Grove at Grand Bay South Tower (Miami, USA) was selected as a case study (Fig. 3). It has 21 floors and a height of 93.8 meters, as shown in Fig. 4b. Analyses were performed by using ETABS (CSI, 2020). The buildings were modeled by using the existing structural and architectural information. The behavior of the structure was investigated under wind and seismic loads.

2. 3-D Finite Element Modelling of Twisted Tall Building Structures

2.1. Structural System of Grove at Grand Bay South Tower

The height of each floor is 13.33 feet (4.064 m) of the building, except for the top floor and podium floor. The angle of rotation on each floor is approximately 3 degrees up to the 15th floor, and the building rotates approximately 39 degrees counterclockwise overall. The Grove at Grand Bay South Tower has 30-inch (762 mm) thick reinforced concrete shear wall with internal steel plate at the core of the building. Steel plates up to 3.75-inches (95.25 mm) thick are placed in the inner part of the shear wall. Rolled steels are used in the boundary zone. The steel plates in the shear wall extend to the 15th floor (Fig. 5). Diameter of a column in a story is 30-inches (762 mm). The concrete strength of the walls and columns in the building is 12,000 psi (82.74 MPa), 10,000 psi (68.95 MPa), and 8,000 psi (55.16 MPa). The longitudinal rebars are B500C- Φ 36 in the building, and S355 steel is used in the steel plate. The floor system consists of a post-tensioned flat plate slab. The thickness of the slab varies from 10 inches (254 mm) to 12 inches (304.8 mm), and the concrete strength of the slab does not exceed 12 ksi (82.74 MPa). The torsion of the building is reduced by using a roof truss system at the top of the building. Tower floor plates are cambered by up to a half-inch (12.7 mm) rotationally. The typical architectural plan of 20th floor is shown in Fig. 6.



Figure 5. Steel Plates Inside the Composite Shear Wall (DeSimone, Ramirez and Mohammad, 2015)

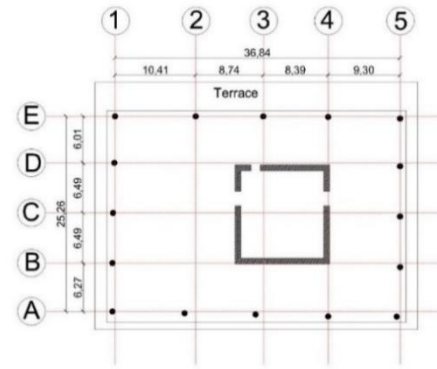


Figure 6. Architectural Plan of the 20th Floor (units are in m)

2.2. Finite Element Modelling and Assumptions

The selected twisted tall building was modified at an angle of three degrees from the first floor to the last floor. The floor plans of the building are shown in Fig.7. 3D finite element models of the prismatic and twisted tall building structures are shown in Fig. 8. The concrete classes are C80/95, C70/85, and C55/67 on the 1-11 level, 12-17 level, and 18-23 level, respectively. The diameter of the circular reinforced concrete columns and the thickness of the composite shear walls are 762 mm. The #11 rebar used in the columns and shear walls is Φ 36 in the metric system. The Grade 75 rebar class used in the selected building is modeled as B500C rebar in the metric system. The composite shear wall was modeled from bottom to top because all floors rotate at an angle. The grade 50 steel class in the internal steel plate was modeled as S355. The I-shaped steel sections in the shear walls were modeled as frame columns and connected to the multi-layer composite shear wall with rigid links. The slabs were modeled as reinforced concrete using C80/95 concrete in the modeling by assigning a rigid diaphragm, and the thickness of the slabs was 11 inches (279.4 mm). The I-shaped steel in the composite columns at the corner points of the shear wall was W 310 x 310 x 283, and the connecting beams between the shear walls were modeled as composite. The hat truss at the top of the structure was ignored in the models. The cambered floors were not considered in the models. All floors were considered the same height (4.064 m). The bottom ends of columns and shear walls were attached to the ground with fixed supports. The soil class was taken from the site class map according to the location of the building (Rong and Thomson, 2012).

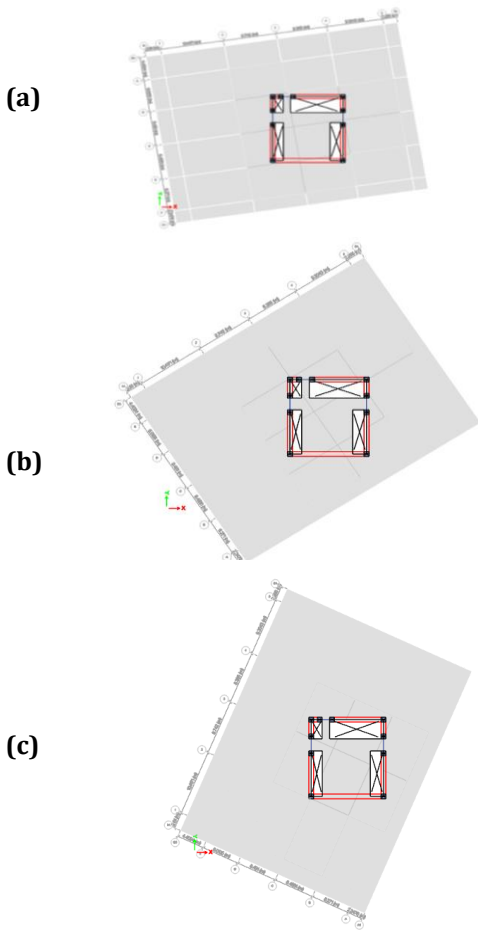


Figure 7. Plans of The Twisted Tall Building: (a) 3rd floor (9-degree rotation); (b) 11th floor (33-degree rotation); (c) 22nd floor (66-degree rotation)

Table 1. Wind Load Parameters for Prismatic Tall Building

Parameter	Value
Wind Speed	76 m/s
Exposure Type	B
Gust Factor (X-Direction)	1.14
Gust Factor (Y-Direction)	1.12

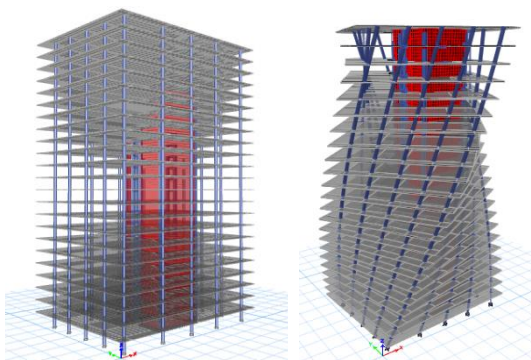


Figure 8. 3-D Finite Element Model of the Prismatic and Twisted Tall Building Structures

Table 2. Assigned Load and Seismic Load Parameters

Parameter	Value
Super Dead Load	76 m/s
Live Load	B
S _s	0,04
S ₁	0,02
Site Class	D
Response Modification (R)	6.5
System Overstrength (Ω)	2.5
Deflection Amplification (C _d)	5.5
Occupancy Importance (I)	1

Super dead load was included in the total weight in the analysis. For seismic loading, the additional %5 accidental eccentricities were included. Figure 9 shows the horizontal elastic design spectrum derived from the following equation 1(ASCE 2017). Because the selected building is flexible, the gust factors are calculated in the x and y direction according to ASCE 7-16(Section 26.11.5). For wind force calculations, the gust factor effect depends on the natural frequency of the building and the building plan dimensions. The gust factor effect (G_f) was calculated 1.14 in the x direction and 1.12 in the y direction. Table 1 and Table 2 show the load parameters in the analysis. The percentage of modal participation was over 90% for the prismatic and twisted tall buildings.

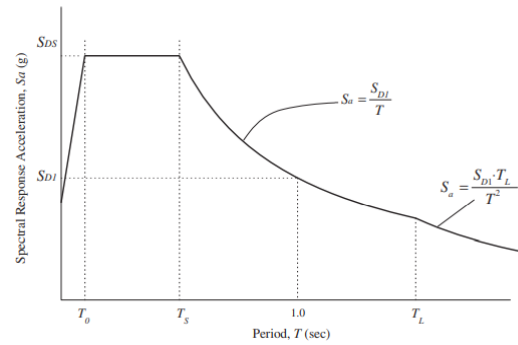


Figure 9. Design Response Spectrum (ASCE 7-16)

$$S_a = S_{DS} \left(0,4 + 0,6 \frac{T}{T_0} \right) \quad T \leq T_0$$

$$S_a = \frac{S_{D1}}{T} \quad T_0 \leq S_a \leq T_s$$

$$S_a = \frac{S_{D1} T_L}{T^2} \quad T_L \leq S_a \quad (1)$$

$$G_f = 0.925 \left(\frac{1 + 1.71 \sqrt{g_Q^2 Q^2 + g_R^2 R^2}}{1 + 1.7 g_v I_z} \right) \quad (2)$$

The composite shear walls in the selected building consist of steel plates and reinforced concrete (Figure 10). The composite shear wall was modeled in ETABS as a shell with a multi-layer shell element (Figure 11). The composite behavior was accounted for by modeling the I-steel-shaped composite corner regions as frames and connecting them to the multilayer shell model with rigid links. The composite shear walls were connected by composite link beams via rigid links.

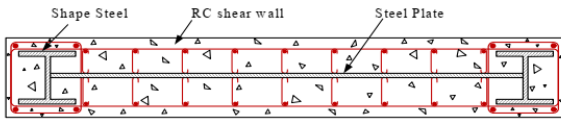


Figure 10. Steel Plate Reinforced Concrete Composite Shear Wall (SPRC) (Xiao et. al., 2012)

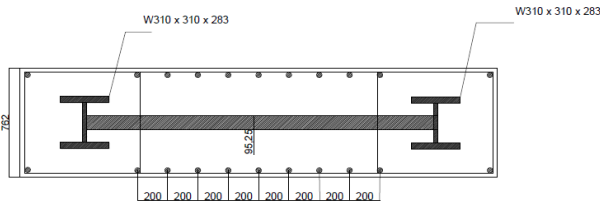


Figure 11. Cross Section Of Composite Shear Wall In Modeling (units are in mm)

3. Results and Discussions

3.1. Base Shear Forces of Models

The base shear in the prismatic tall building is 4263 kN under the seismic load cases in X and Y directions under seismic load. The value of base shear is 14497 kN in the X direction and 19597 kN in the Y direction. The base shears of models are shown in Table 3. Under seismic load cases in X and Y directions, the value of base shear is 4245 kN in twisted tall building. Base shear is 12323 kN in the X direction and 16658 kN in the Y direction of wind load in twisted tall building.

Table 3. Base Shear Forces

Load Type	Prismatic Tall Building	Twisted Tall Building
Seismic Load	X: 4263 kN	X: 4245 kN
	Y: 4263 kN	Y: 4245 kN
Wind Load	X: 14497 kN	X: 12323 kN
	Y: 19597 kN	Y: 16658 kN

3.2. Seismic Behaviour of Prismatic Tall Building Structures

The response spectrum analysis was performed for the seismic analysis. The seismic load was applied in both X and Y directions for the model, separately in each case.

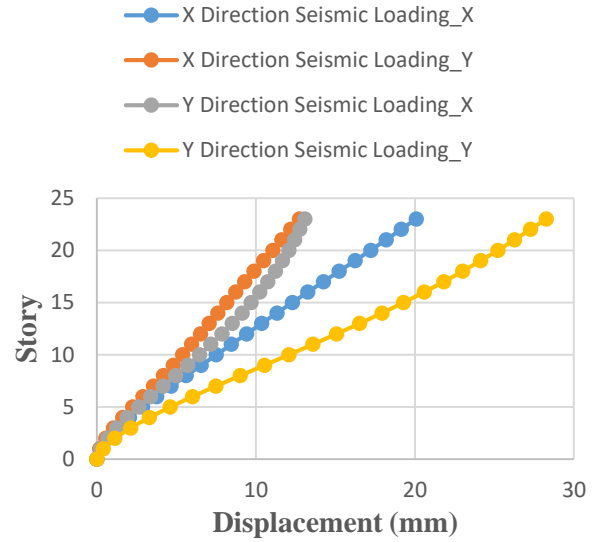


Figure 12. Top Story Displacements Under Seismic Load Case

The maximum top deflection is 2.0 cm under seismic loading in the X direction and 2.8 cm under seismic loading in the Y direction (Figure 12). The story drift values of the model are shown in Figure 13. The maximum drift is 6.3 mm for seismic loading in the X direction and 8.6 mm for seismic loading in the Y direction. The maximum overturning moments in the X-direction and Y-direction are found 1.69×10^5 kN.m and 2.46×10^5 kN.m, respectively, in Figure 14.

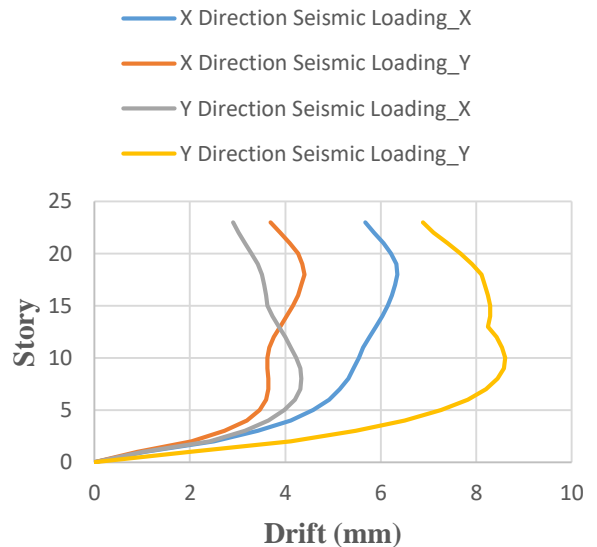


Figure 13. Story Drifts Of The Model Structure Subjected To The Seismic Load

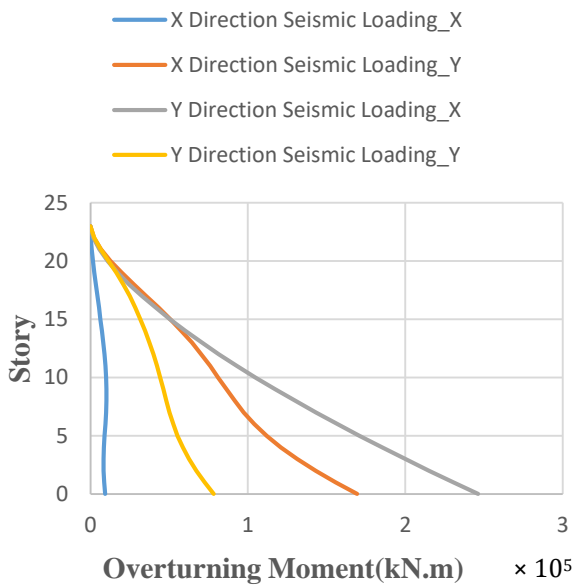


Figure 14. Overturning Moment Under Seismic Load Case

3.3. Wind Load Case and Behaviour of Prismatic Tall Building Structures

The code-based wind loading was used in the wind analysis. The wind load was applied in both X and Y directions, separately. The maximum displacement of the top story under wind load in X and Y directions is shown in Fig. 15 for each floor of the prismatic tall building. The maximum displacement of the top floor is 6.9 cm in the X-direction and 11.1 cm in the Y-direction under wind load. According to the literature, the maximum lateral displacement of tall buildings should not exceed the ratio H/500 (Serviceability criteria).

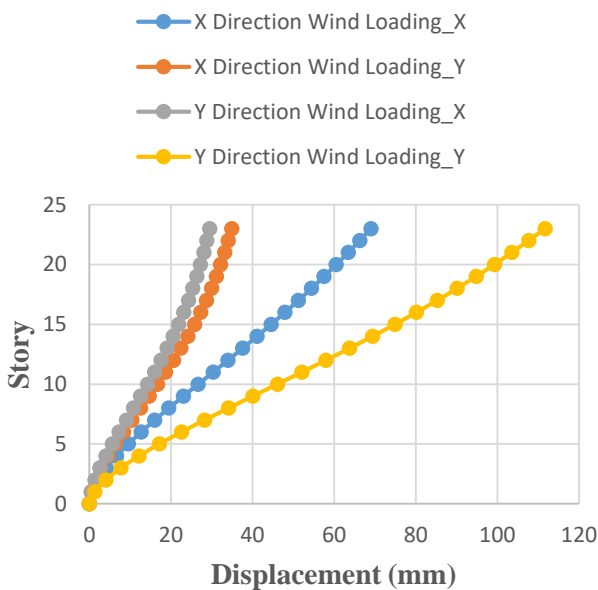


Figure 15. Top Story Displacements Under Wind Load

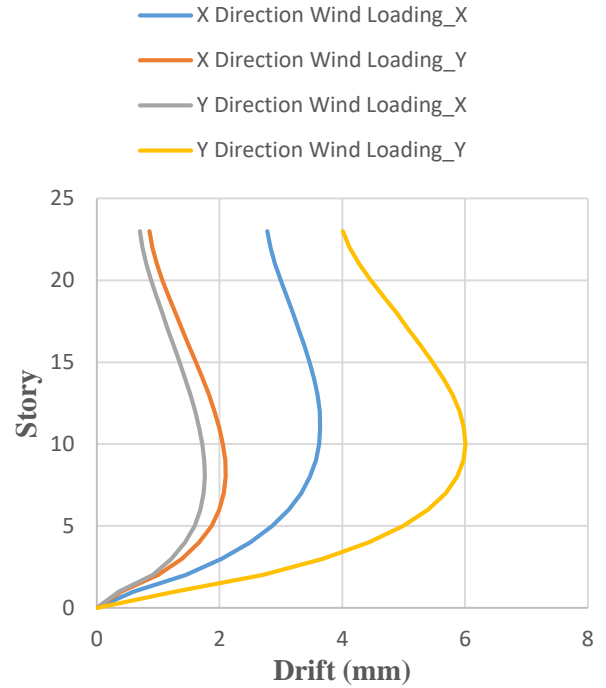


Figure 16. Story Drifts Of The Model Structure Subjected To The Wind Load

Top deflections under wind load are below the serviceability criteria, which is 18.7 cm. The maximum drift is 3.64 mm under wind loading in the X direction and 6 mm under wind loading in the Y direction (Figure 16). The maximum overturning moment values for wind loading in the X direction and wind loading in the Y direction are found 7.36×10^5 kN.m and 9.92×10^5 kN.m, respectively (Figure 17).

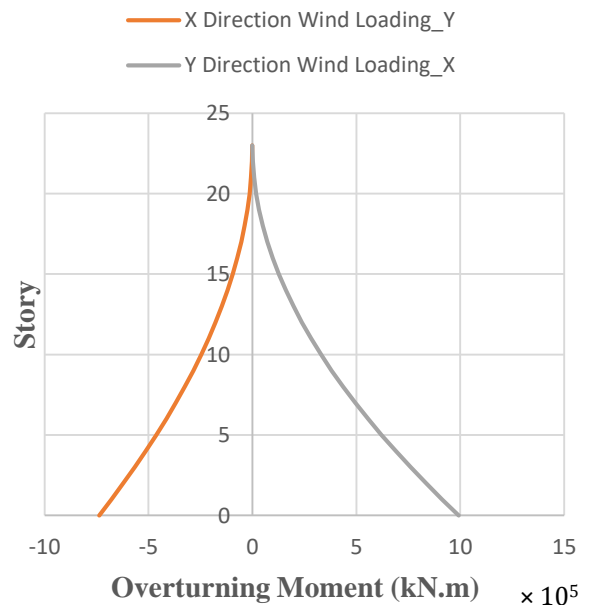


Figure 17. Overturning Moment Under Wind Load Case

3.4. Seismic Behaviour of Twisted Tall Building Structures

The seismic analysis in twisted tall building, response spectrum analysis was carried out. In each case, the seismic load was applied in both the X and Y directions separately. Under seismic loading, the maximum upper deflection is 2.6 cm in the X direction and 2.9 cm in the Y direction (Figure 18). Figure 19 shows the results of the drift of the model relative to the floors. The maximum drift for seismic load in the X direction is 8.36 mm, while the maximum drift for seismic load in the Y direction is 8.8 mm. It is observed that there are increases in story drifts between 16-23. level. The maximum relative displacement value for the earthquake force is calculated 81.28 mm under ASCE 7-16 standard. Figure 20 shows the maximum overturning moment values in the X and Y directions 1.71×10^5 kN.m and 2.42×10^5 kN.m, respectively. Maximum overturning moment of X axis in X direction is found 0.0636×10^5 kN.m. Maximum overturning moment of Y axis in Y direction is found 0.75×10^5 kN.m.

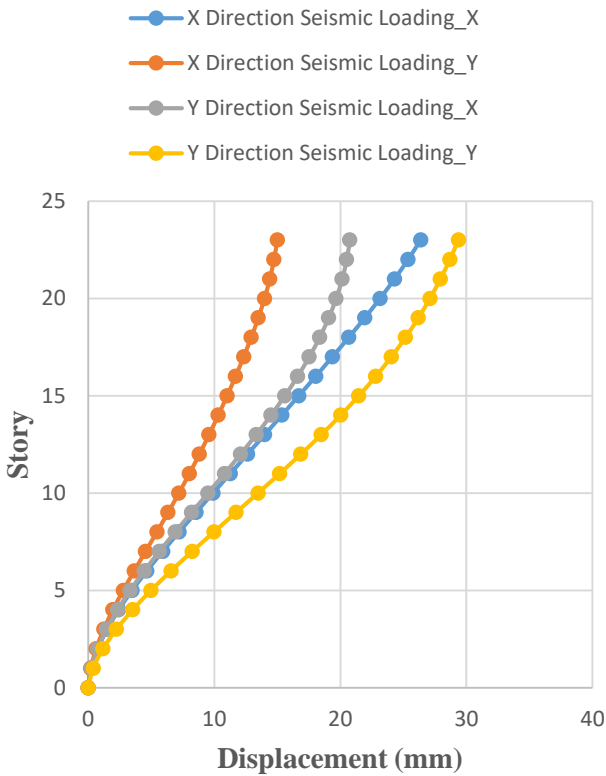


Figure 18. Top Story Displacements Under Seismic Load Case

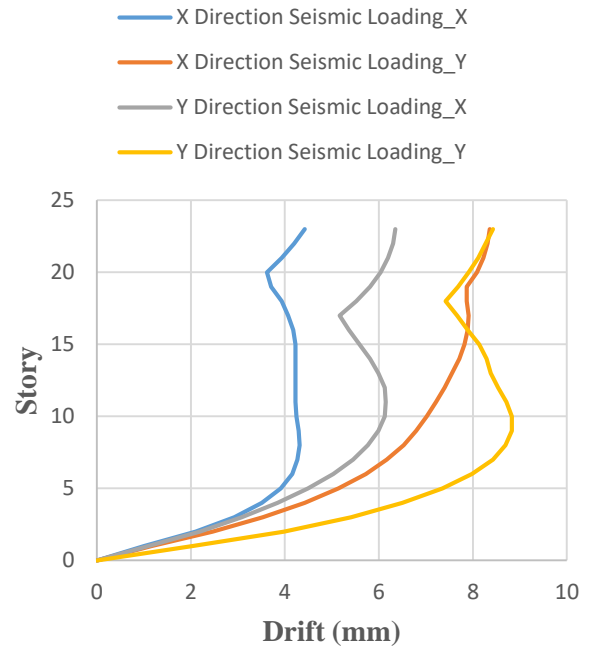


Figure 19. Story Drifts Of The Model Structure Subjected To The Seismic Load

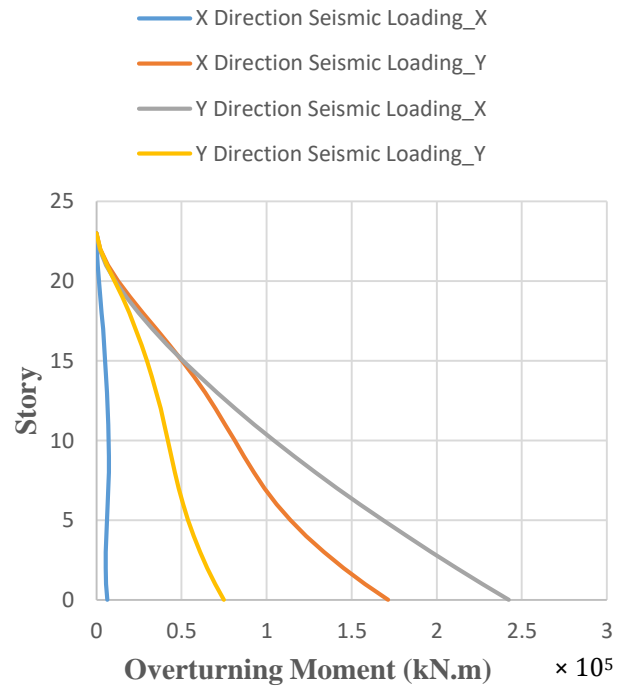


Figure 20. Overturning Moment Under Seismic Load Case

3.5. Wind Load Case and Behaviour of Twisted Tall Building Structures

In the literature, it is known that twisted tall building structures play an active role in reducing wind loads (Bilgen, 2019). In this study, the wind forces occurring in the prismatic structure were applied by reducing 15% in the twisted tall building structure (Niğdelioğlu, 2022). The wind load was applied in both the X and Y directions. The maximum displacement of the top floor under wind load in X and Y directions is shown in Fig. 21 for each floor of the twisted tall building. The maximum displacement of the top floor under wind load is 6.8 cm in the X direction and 9.6 cm in the Y direction. In the literature, the maximum lateral value of the structures is generally given as the H/500 ratio. The upper deflections under wind load are lower than the serviceability criterion, which is 18.7 cm. Under wind load, the maximum drift is 3.55 mm in the X direction and 5.129 mm in the Y direction. (Figure 22). Figure 23 shows the maximum overturning moment values for the wind load in the X-direction and the wind load in the Y-direction, which are 6.25×10^5 kN.m and 8.43×10^5 kN.m, respectively.

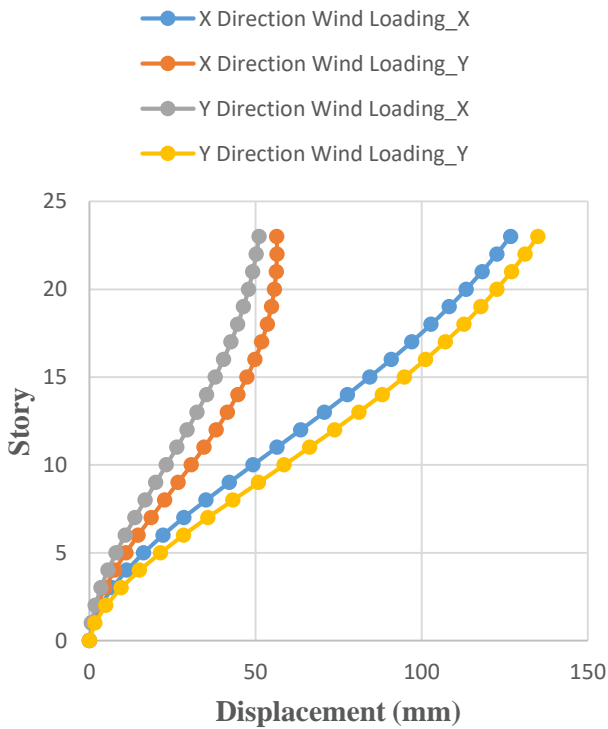


Figure 21. Top Story Displacements Under Wind Load Case

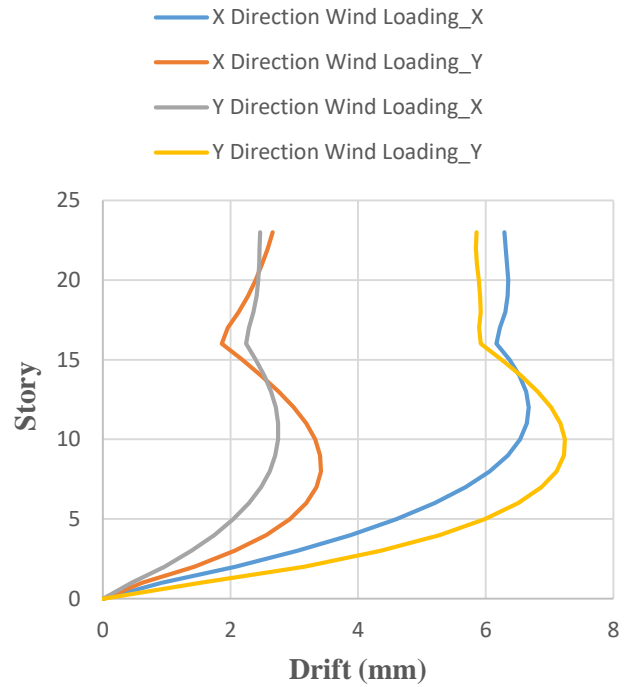


Figure 22. Story Drifts Of The Model Structure Subjected To The Wind Load

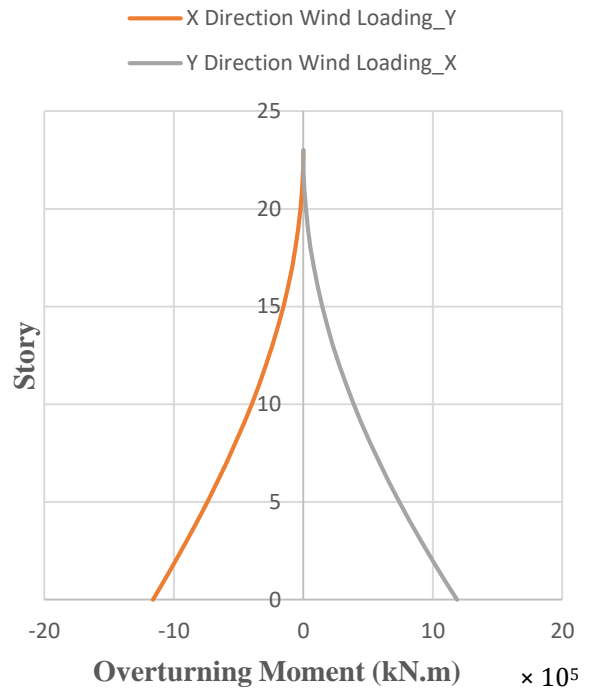


Figure 23. Overturning Moment Under Wind Load Case

4. Conclusion

This paper presents a finite element model for the analysis of twisted tall building structures under lateral loads and a corresponding prismatic tall building. The Grove at Grand Bay South Tower was used as a case study and the behaviour of the building under lateral loads was investigated and compared. Results include maximum story displacements, maximum inter-story drifts, base shear, and overturning moments. The maximum story displacement values under wind and seismic loading for prismatic and twisted tall buildings are less than $H/500$ of the building height. The twisted building is within the allowable deflection criteria. The drift values under wind and earthquake loading are within the criteria of ASCE 7-16. Since the twisted structure has an irregular form, the percentage of modes exceeds 90% when 17 modes are considered in the analysis. With 11 modes in the prismatic structure, the mod participation rate value of 90% exceeds. The maximum story displacements under seismic load are lower than under wind load, because wind load is more critical than seismic load. The base shear values under wind loads are higher than under seismic loads because the location of the building isn't an earthquake-prone region. The twisted tall building has maximum relative displacement of 8.36 mm in the x-direction, whereas the prismatic tall building has a maximum relative displacement of 6.3 mm. It is also found that the overturning moment values are higher under wind loads. It is observed that the relative displacements increased on the 16-23rd floors of the twisted tall building compared to the prismatic structure. The increase in relative displacement on these floors can be considered as the reason that the existing building is not rotated on these floors. In the study, the lateral stiffness of the twisted tall building under earthquake loading is lower than the prismatic tall building. The twisted form of the building has contributed to the decline in wind force compared to the prismatic form of the building. In addition, the wind load in Y direction is bigger than X direction in both building forms. In order to better analyze the wind force distribution in twisted tall buildings, it is recommended to apply the wind to the facade of the building via wind tunnel tests and computational fluid dynamics studies in next future studies.

Author Contributions

In this paper; Abdullah Niğdelioğlu, modelling of the buildings, writing, literature survey; Uğur Albayrak, conceptualized the paper, supervision; Can Balkaya conceptualized the paper, supervision and reviewed the manuscript.

Conflict of Interest

No conflict of interest was declared by the authors.

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INFLUENCES OF GRINDING CONDITIONS ON GALENITE-SPHALERITE FLOTATION KINETICS

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Keywords

Flotation,
Dry grinding
Wet grinding

Abstract

Grinding is more than just crushing, it is also a process that causes a chemical reaction on the surface of the mineral. Water used in the grinding process significantly affects the galvanic interaction.

Different grinding conditions result in different pulp chemistries. This becomes especially important in sulfide flotation in terms of recovery and selectivity. There are limited studies examining the effects of dry and wet grinding prior to the flotation of sulfide minerals. This study compared the effects of wet and dry grinding on the flotation kinetics of complex Pb-Zn sulfide ore at P_{80} of 20 and 50 μm grind sizes. Results showed that dry grinding positively affected the sphalerite ore flotation compared to wet grinding in terms of recovery and grade in both galenite and sphalerite rougher flotation stages. Considering that the effect of dry grinding was due to the difference in pulp chemistry, the reasons were explored based on particle morphology, and pulp potentials.

The results showed that grinding the same ore under dry and wet conditions significantly affected the flotation performance. In light of the pulp potential measurements, it was determined that the reducing environment obtained in the wet grinding negatively affected the flotation performance, while the oxidizing environment formed during the dry grinding affected the flotation performance positively. This was attributed to the fact that galvanic interactions that occurred during wet grinding were significantly reduced during dry grinding. Hence, better galenite and sphalerite flotation was obtained following dry grinding.

ÖĞÜTME KOŞULLARININ GALENİT-SFALERİT FLOTASYON KİNETİĞİ ÜZERİNDEKİ ETKİLERİ

Keywords

Flotasyon,
Kuru öğütme
Yaş öğütme

Öz

Öğütme, sadece kırmanın ötesinde, mineralin yüzeyinde kimyasal reaksiyona neden olan bir işlemdir. Öğütme işleminde kullanılan su, galvanik etkileşimi önemli ölçüde etkiler.

Farklı öğütme koşulları, farklı pülp kimyalarının oluşmasına neden olmaktadır. Bu durum özellikle sülfürlü mineral flotasyonunda verim ve seçicilik açısından önem arz etmektedir. Flotasyon öncesi kuru ve yaş öğütmenin, sülfürlü mineral flotasyonu üzerindeki etkilerini inceleyen sınırlı sayıda çalışma bulunmaktadır. Bu çalışmada, yaş ve kuru öğütmenin P_{80} 20 ve 50 μm tane boyutundaki kompleks sülfürlü galenit-sfalerit flotasyon kinetiği üzerindeki etkileri karşılaştırılmıştır. Sonuçlar, kuru öğütmenin hem galenit hem de sfalerit flotasyon devrelerinde verim ve tenör açısından yaş öğütmeye kıyasla flotasyon performansını olumlu etkilediğini göstermiştir. Gözlemlenen olumlu etkinin pülp kimyasındaki farklılıktan kaynaklandığı düşünülerek sonuçlar tane

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morfolojisi ve pülp potansiyeli özelinde araştırılmıştır. Sonuçlar, önceki çalışmada kullanılan 50 µm boyutundaki numunelerin galenit flotasyon devresinden elde edilen sonuçları ile karşılaştırmalı olarak verilerek tartışılmıştır.

Elde edilen bulgular, aynı cevherin farklı koşullar altında öğütülmesinin flotasyon performansı üzerinde önemli etkileri olduğunu göstermektedir. Pülpün elektrokimyasal ölçümleri ışığında yaş öğütmede oluşan indirgeyici ortamın flotasyon performansını düşürdüğü belirlenmiştir. Kuru öğütme işlemi sırasında yeni açığa çıkan mineral yüzeyleri su, pH veya E_h gibi kimyasal reaksiyonlardan etkilenmez ve böylece flotasyon verimi olumlu yönde etkilenir. Öğütme sırasında oluşan oksitleyici ortam nedeniyle galenit-sfalerit minerallerinin yüzebilirliği artmaktadır.

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1. Introduction

In dry areas such as South Africa, Australia, Chile and China, water depletion has a significant negative impact on the environment, which is becoming more pronounced due to the high consumption level of water (Franks, Forbes, Oshitani, Batterham, 2015; Gunson, Klein, Veiga, Dunbar, 2012; Kökkiliç, Langlois, Waters, 2015; Nguyen, Ziemiński, Vink, 2014; Rivas-Perez, Sotomayor-Moriano, Perez-Zuñiga, 2017). Besides these regions, countries such as Sweden have procedures to conserve and recycle water in mining operations to obtain better resource usage and environmental benefits (Ranängen and Lindman, 2017; SIP STRIM, 2019). In this context, the use of dry grinding systems gains importance. A limited number of studies comparing the effects of dry and wet grinding on flotation in complex sulfide ores are included in the literature (Feng and Aldrich, 2000; Seke, 2005; Başaran, 2006; Chapman, Shackleton, Malysiak and O'Connor, 2013).

In this study, the effects of dry and wet grinding on the flotation kinetics of complex Pb-Zn sulfide ore were examined comparatively in the case of two different grind sizes, emphasizing particle morphology and pulp potential change.

2. Literature Review

2.1. Dry and Wet Grinding

In mineral processing, wet grinding is preferred to dry grinding because of the ease of material handling and higher energy efficiency in wet grinding. It is known that wet grinding requires less energy consumption than dry grinding i.e., about 20-25 % lower compared to wet grinding. As a result of wet grinding, products with the desired surface formation and less deformation of the particle surface are obtained (Feng and Aldrich, 2000).

On the other hand, dry grinding has many advantages, including less wear of the grinding media than wet grinding, a smaller proportion of fine products, and the potential to improve downstream process efficiency (Bruckard, Sparrow and Woodcock, 2011; Kanda, Abe, Yamaguchi and Endo, 1988; Koleini, Abdollahy and Soltani, 2012; Ogonowski, S., Wołosiewicz-Głab, M., Ogonowski, Z., Foszcz, D., Pawełczyk, F., 2018; Routray and Swain, 2019)

In an experiment with sphalerite mineral that was crushed by a high-pressure roller mill (HPGR) or conventional methods and wet ground by rod mill, it was observed that the highest sphalerite recovery and grade values were obtained after dry grinding regardless of the crushing method (Figure 1)(Chapman et al., 2013). In parallel with these results, Seke (2005) showed that higher sphalerite recovery values and positive pulp potential were obtained as a result of dry grinding compared to wet grinding.

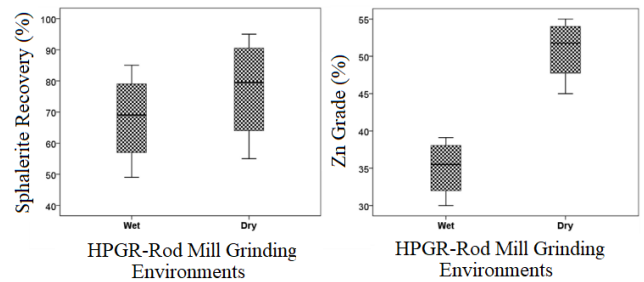


Figure 1. Flotation Performance of Sphalerite in Different Grinding Environments (Chapman et al., 2013)

Figure 2 shows the time-dependent changes in lead and zinc recovery of the ore from the Rosh Pinah mine under different grinding conditions (50 g/t sodium n-propyl xanthate (SNPX)). It is seen that zinc recoveries after dry grinding are higher and lead recoveries are lower

compared to wet grinding. One of the reasons for the lower zinc recovery after wet grinding may be that the steel is more anodic than sphalerite, resulting in electron flow from steel to sphalerite (Seke and Pistorius, 2006). These electrons cause the formation of hydroxyl ions by reacting with water, and hydroxyl ions can react with metal ions in the environment to form stable metal hydroxides on the mineral surface, and as a result, they can make the mineral surface hydrophilic or reduce its suitability for collector absorption (Palm et al., 2010).

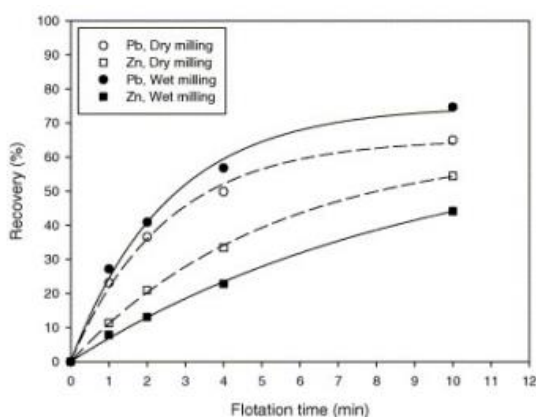


Figure 2. Flotation Recovery of Galenite and Sphalerite Under Various Grinding Conditions (Seke and Pistorius, 2006).

In another study conducted with complex sulfide ores, it was stated that particle surface deterioration occurred as a result of the exposure of particles with denser pulp (90% solids) in the dry grinding process to higher stress. In addition, as a result of new surface formation, it has been observed that dry milling consumes more energy compared to wet milling. This indicates that more energy is conserved in the surface deterioration resulting from dry grinding. Surface weathering plays an important role in the subsequent particle dissolution and reactive absorption (Feng and Aldrich, 2000). In this context, it was determined that the SIBX (Sodium Isobutyl Xanthate) absorption kinetics of dry ground activated mineral surfaces were faster.

Dry-ground samples have higher surface energy and faster flotation kinetics compared to wet grinding, while wet-ground samples provide higher grades and slightly higher recovery values. Dry grinding creates activated layers on the particle surface by causing high stress on the particles. On the other hand, grinding in an aqueous medium increases the sample's surface area. Feng and Aldrich (2000) pointed out the improvement in flotation kinetics and grade due to the combined use of wet and dry grinding.

2.2. Pulp Potential

Pulp potential is one of the important electrochemical parameters that can be associated with flotation efficiency and can be used in many situations, such as the oxidation/reduction control of minerals in the pulp. The pulp potential can be used to determine the surface conditions of sulfide minerals and to estimate the optimum flotation conditions.

The potential measured in the flotation system is the mixing potential and is somewhere between the mineral and solution potential values. The separation of the minerals in the flotation stage depends on the pulp potential (Trahar, 1984; Richardson and Walker, 1985).

Electrochemical studies using mineral electrodes with high purity sulfide mineral samples have shown that the interaction of a mineral with the collector can be controlled by the electrochemical potential measured at the mineral surface (Buckley and Woods, 1982; Allison, Gould, Nicol and Granville, 1972; Ruonal, Heimala & Jounela, 1997).

The potential value of the flotation pulp cannot be easily estimated due to galvanic interactions occurring in the system (Rao, Moon and Leja, 1976; Martin, McIvor, Finch and Rao, 1992). It has been observed that the pulp potential values vary between +50 and +200 mV in the applications made in the facilities where sulfide mineral flotation takes place (Grano, 2004).

Pulp potentials in aerated systems are too oxidizing to provide maximum mineral separation by flotation. For each mineral, there is a unique potential value at which flotation begins. The recovery values corresponding to the changing potential value of the galenite are shown in Figure 3. Galenite floats at values between 0 and 410 mV (SHE), the flotation efficiency is quite low below and above these values. By determining and controlling the pulp potential ranges in which the minerals float, these minerals can be selectively separated from each other. However, at very anodic potential values, specific ranges of values may overlap and cause simultaneous floating of some minerals, reducing selectivity (Ralston, 1991; Chander, 2003). By observing the potential changes in the flotation cell, the addition points of the reagents can be determined, and the grade and recovery values can be increased (Chander, 2003). In addition, the collection of E_h -pH data allows for obtaining additional information that can help reduce reagent quantities and solve problems in flotation plants (Johnson and Munro, 1988).

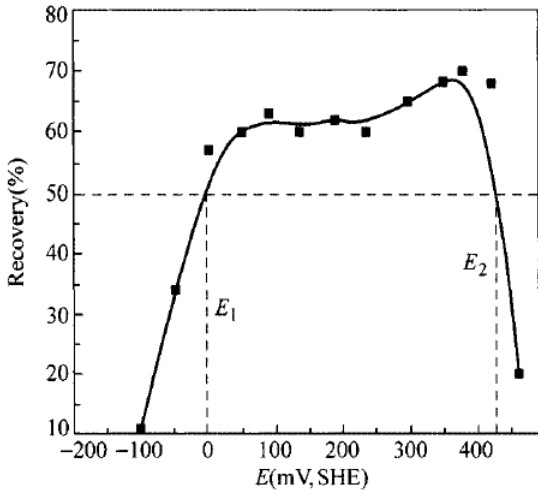


Figure 3. Galenite Recovery versus Pulp Potential (Hu et.al.,2010)

Due to the high electrical resistivity of sphalerite, very few studies have examined its electrochemical behavior. The relationship between sphalerite recovery and pulp potential is shown in Figure 4. Sphalerite flotation takes place between 0 and 310 mV (SHE) values.

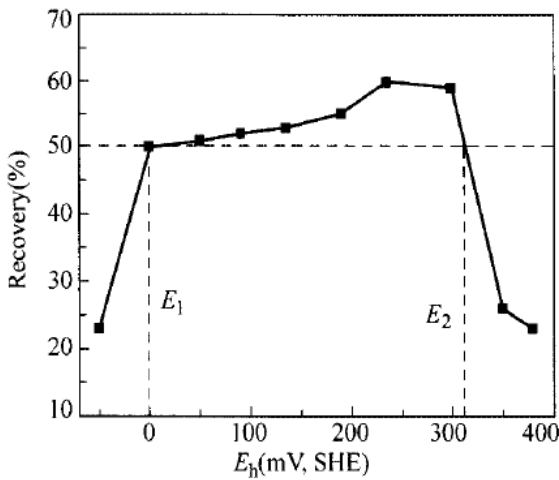


Figure 4. Sphalerite Recovery versus Pulp Potential (Hu et.al., 2010)

In many of the sulfide mineral systems, the pulp potential values reach more reducing (cathodic) values, that is, decrease as the dissolved oxygen moves away from the system. It has been observed that the pulp potentials are very low since sulfide minerals are mostly ground in steel mills (Woodcock and Jones, 1970 a, b; Graham and Heathcote, 1982; Grano et al., 1994). Since the absorption of thiol collectors depends on the E_h values, the floatability of the minerals can be greatly

reduced if adequate aeration is not provided before flotation.

The oxidation of the medium, which reacts with oxygen, continues until the oxygen in the mill is depleted. Afterward, while a sudden decrease in pH values is observed, hydroxyl ions begin to form on the mineral surfaces. The reducing effect of the interaction between the grinding medium and sulfide minerals on the flotation pulp has been included in many studies (Forssberg and Subrahmanyam., 1993; Leppinen, Hintikka and Kalapudas., 1998; Martin et al., 1992; Yuan et al., 1996 a,b).

The pulp potential change of the lead-zinc sulfide ore belonging to the Rosh Pinah Mine, which is ground dry and wet in the steel mill, is shown in Figure 5. Dissolved oxygen and pulp potential were higher after the dry grinding of the composites. Similar results were observed in the study of Koleini et al. (2012). The increase in pulp potential with the onset of aeration is clearly due to the increase in the amount of oxygen in the pulp.

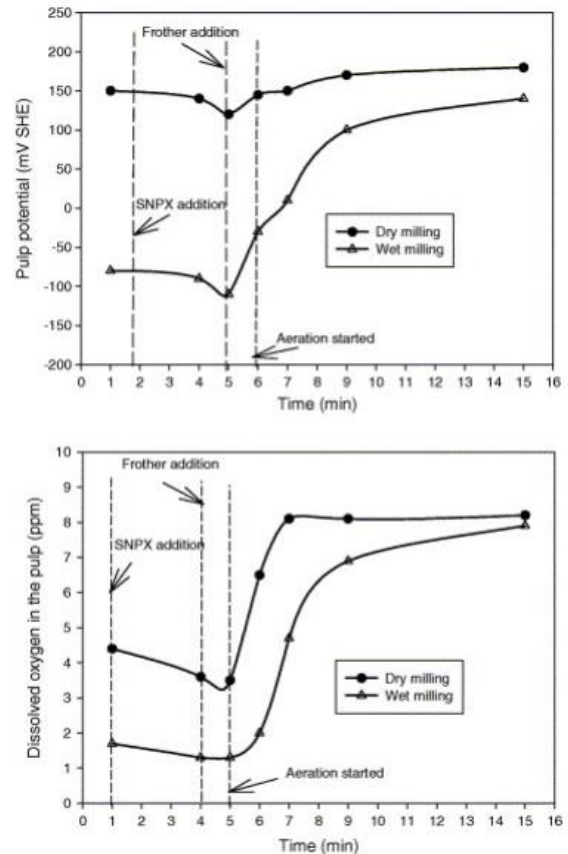


Figure 5. Effect of Dry and Wet Grinding on Pulp Potential and Dissolved Oxygen (Seke and Pistorius, 2006).

After dry grinding, further oxidation of minerals is inevitable due to aeration in the flotation cell. On the contrary, more negative pulp potential values and lower dissolved oxygen content are detected in wet grinding. Under these conditions, less oxidation of minerals occurs during conditioning. It is known that the flotation of sphalerite in complex lead-zinc ores increases under oxidized conditions. Therefore, it can be expected that the flotation efficiency of sphalerite will increase and the selectivity between lead-zinc will decrease after dry grinding. The presence of dissolved oxygen in the environment improves the flotation efficiency of sphalerite by depressing pyrite and preventing the formation of hydrophobicity on the mineral surface (Ek, 1985; Bulatovic and Wyslouzil, 1985; Dávila-Pulido, Uribe-Salas and Espinosa-Gómez, 2011).

3. Material and Method

3.1. Material

The sample studied was complex Pb-Zn sulfide ore originating from South America. Chemical analyses of the sample were performed using the multi-element inductively coupled plasma optical emission spectrometry (ICP-OES) method carried out by Bureau Veritas Commodities Canada Ltd. The chemical analysis is given in Table 1. The ore contains sulfur minerals, principally galenite (PbS), sphalerite (ZnS), pyrite (FeS₂), and minor amounts of chalcopyrite (CuFeS₂). The lead mineral in the ore consists of 99% galenite, while the zinc mineral consists of 98.78% sphalerite. The primary iron minerals are goethite (FeO(OH)), which accounts for 81.64% of the total, with hematite and pyrite accounting for the remainder.

Table 1. Chemical Analysis of the Flotation Feed (Tokcan, 2017)

Pb	Zn	Fe	Cu	S	Ag
%	%	%	%	%	g/t
1.07	2.74	23.22	0.08	2.65	24.00

3.2. Method

3.2.1. Grinding Tests

The crushed ore sample was utilized in wet grinding (WM) while part of it was dry ground (DM) by the pilot scale Loesche GMBH vertical roller mill system in Germany (P₈₀: 50 and 20 µm) and delivered to Eskişehir Osmangazi University, Mining Engineering Department Mineral Processing Laboratory. Samples to be ground by wet grinding for P₈₀ 50 µm (DM-50) and P₈₀ 20 µm (DM-

20), and also dry ground samples were kept frozen to avoid surface oxidation after riffing.

A stainless steel rod mill (Ø200x 250 mm) with 12.9 kg of stainless-steel rods was used to grind bulk samples used in wet grinding at 60% solids. Wet ground samples were ground for 85 minutes to obtain a P₈₀ of 20 µm (WM-20) and for 52 minutes to obtain a P₈₀ of 50 µm (WM-50). In wet grinding experiments, depressants and lime were added to the mill with the sample to affect the newly formed mineral surfaces and maintain the pH.

3.2.2. Particle Size Analysis

A particle size measurement device Malvern Mastersizer Hydro 2000 MU-Malvern Co., Ltd., UK working with the laser diffraction method was used for the particle size analyses. At the end of each wet grinding test, samples were taken with the help of a syringe from the conditioned pulp in the flotation cell.

3.3.3. Scanning Electron Microscopy (SEM) Analysis

SEM analyzes of dry and wet ground samples were carried out at the Anadolu University Ceramic Research Center. The Zeiss Supra VP50 model SEM device was used in the measurements.

3.3.4. Image Analysis

The shape characterization was performed at Cumhuriyet University Mining Engineering Laboratory with a Particle Insight Dynamic Image Analyzer, One Micromeritics Drive, Norcross, GA30093-1877.

Many methods have been developed to characterize the shape of the particles. One of the scientific methods that analyze the shape parameters of the particles is the image analysis method which is frequently used. The Particle Insight Analyzer uses two important features: random routing and recirculation of samples. These features help obtain precise data about the sample and give its true description. Roundness is calculated using the area (A) and the radius of the bounding circle (DBC) (Equation 1). This measurement is fractional, with perfect roundness expressed as 1. The closer the value is to 1, the more rounded it is. The roundness value is not affected by the minor irregularities around the particle and the errors in the circumference measurement.

$$\text{Circularity} = 4A / \pi DBC^2 \quad (1)$$

An Ellipse Length Ratio (EEL) is calculated using equivalent ellipse area length and width values. Smoothness refers to the measurement of regional

fluctuations around the particle cross-section. A value of 1 indicates that there is no roughness on the surface, while lower values indicate that the roughness on the surface is increasing.

3.3.5. Kinetic Flotation Tests

Batch flotation tests were conducted using the Denver D12 type with an impeller speed of 1,300 rpm at an air flow rate of $6 \text{ dm}^3 \text{ min}^{-1}$ and a 2,5 L flotation cell. All flotation tests were conducted at about 35% solids. In the galenite flotation stage, the slurry pH was set at 8, and lime was used in solid form to adjust the pH. Aerophine 3418A (3418-A) and Aerofroth 70 (AF-70) from Solvay Chemicals were utilized as collector and frother respectively. Sodium metabisulfite ($\text{Na}_2\text{S}_2\text{O}_5$) and sodium cyanide (NaCN) were used as sphalerite and pyrite depressants. The froth was scraped into separate pans at intervals of 1, 3, 5, 7, 10, and 12 minutes.

In the sphalerite flotation stage, the slurry pH was set at 11. Sodium isopropyl xanthate (SIPX) and copper sulfate (CuSO_4) were used as sphalerite collectors and activators, respectively. The froth was scraped at intervals of 1, 3, 5, 7, and 10 minutes. The effects of particle sizes P_{80} of 50 μm and P_{80} of 20 μm on galenite and sphalerite flotation kinetics were investigated in the cases of dry and wet grinding conditions.

In both flotation stages, the flotation rate constants (k) were also calculated to compare the effect of different grinding conditions based on a classical first-order flotation kinetics model (Equation 2).

$$R = R_{\max}(1 - e^{-kt}) \quad (2)$$

where, R is the calculated recovery, R_{\max} is the theoretical maximum recovery, k is the flotation first-order rate constant, and t is time.

3.3.6. Pulp Potential Measurements

A Hach HQD Portable Meter with a pH and platinum ORP electrode was utilized to monitor the pH and pulp potential (E_h) values throughout the flotation tests. The measured potential values were converted from the Ag/AgCl scale to the SHE (Standard Hydrogen Electrode) scale using Equation 3.

$$E_{\text{SHE}} = E_{\text{Ag/AgCl(volt)}} + 0.207 \quad (3)$$

The research has been prepared by analyzing in accordance with publication ethics.

4. Results

4.1. Particle Size Analysis

Particle size analysis data of dry and wet ground galenite-sphalerite ores measured by laser diffraction method are presented in Figure 6. 50 μm sized samples that were used in the previous study (Tokcan and Bozkurt, 2021) were shown in grey color in the graphics.

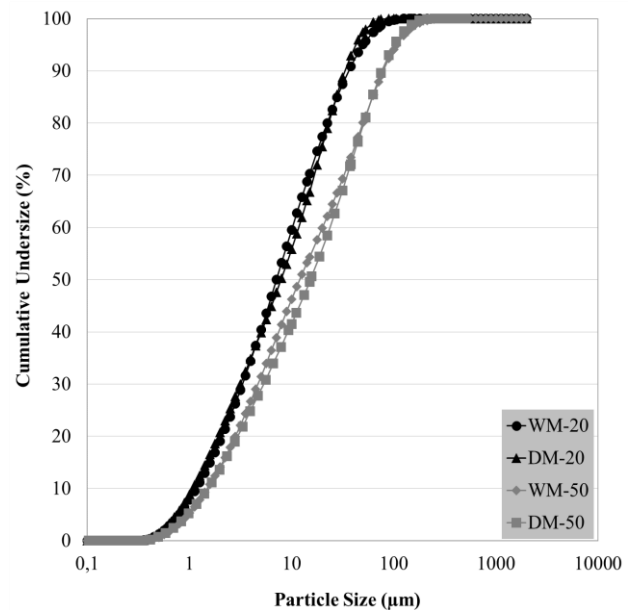


Figure 6. Particle Size Analysis of Samples (Tokcan, 2017)

The particle size distributions of the samples ground under different conditions are quite similar. Therefore, it is assumed that the flotation performance differences are related to the differences between dry and wet grinding.

4.2. Effect of Grinding Conditions on Particle Shape and Morphology

Unlike other separation processes, flotation is directly affected by the surface properties of minerals and thus by the grinding process. The deformation mechanism that takes place in grinding has a significant effect on the mineral surface properties. Ocepek, Strazisar and Kanduti-Sumej (1990) found that the way flotation reagents react with minerals depends on how different the surface shapes of the minerals are.

Different breaking mechanisms of traditional tumbling mills change the surface properties, such as physical, chemical, and roughness, differently. These changes can vary according to the material and mill characteristics, the grinding method, ambient temperature, and

pressure (Orumwense and Forssberg, 1991). The surface roughness of the particles can affect flotation performance after grinding. The particle shape and morphology of the product obtained during the grinding process should be examined using image analysis systems to examine the effects of the enrichment process and to predict their behavior (Petruk, 1986, 1988, 1989; Jones, 1987).

The effects of different grinding schemes (VRM versus Rod Mill) on particle shape and morphology were investigated. The effect of different grinding mechanisms on the particle shape was examined with a Particle In-sight Analyzer to determine the roundness, smoothness, and EEALs. The data for the aforementioned shape parameters is shown in Table 2.

Table 2. Particle Shape Analysis Results (Tokcan, 2017)

Sample	C.P.	CIRC	S.D.	S.	S. D.	EEAL	S. D.
WM	6530	0.63	0.12	0.84	0.08	1.66	0.33
DM	6436	0.64	0.11	0.83	0.07	1.64	0.31

C.P.: Counted Particles
 S.: Smoothness
 CIRC:: Circularity
 S.D.: Standard Deviation
 EEAL: Ellipse Length Ratio

As a result of the examinations, it was observed that slightly more rounded and rougher particles were obtained after dry grinding, and relatively longer and smoother particles were obtained after wet grinding. The difference between the particle characteristics was quite negligible when comparing different grinding schemes, confirming that the main difference in flotation response would be due to the dry and wet grinding conditions. In the literature, it has been observed that the samples ground in the rod mill have a longer particle shape compared to the ball and autogenous mills (Yekeler, Ulusoy and Hıçyılmaz, 2004). It is also among the findings that the high liberation and round particle shape obtained in autogenous grinding provide a high concentrated grade and higher recovery values (Forssberg and Zhai, 1985). On the other hand, the low floatability of the mineral was attributed to the round shape of the particles (Hoberg and Schneider, 1978). It has been shown that the separation of round particles from the air bubble is higher compared to particles with a high length ratio (Wotruba, Hoberg and Schneider, 1991). As it is understood, studies on the effects of particle shape on flotation performance are contradictory to each other. Particle morphologies vary depending on the ore type, grinding mechanisms, and grinding times.

It is stated in the literature that, as a result of dry grinding, the particle surfaces are rougher than those after wet grinding (Feng and Aldrich, 2000). Dry ground

samples have faster flotation kinetics compared to wet ground samples. The performance of dry grinding is higher than wet grinding, both on a recovery and grade basis. It is thought that the defects occurring on the mineral surfaces after dry grinding make the surface more suitable for collector adsorption and thus increase the flotation efficiency. From this point of view, the wet grinding sample with a smoother surface has lower surface energy, so it is expected that the flotation kinetics will be slower (Feng and Aldrich, 2000).

As indicated before, there are slight differences in shape analysis. SEM images were examined in detail for each fraction to visually find any difference. However, when the SEM images of dry and wet samples were compared, no noticeable difference was found between them (Figure 7).

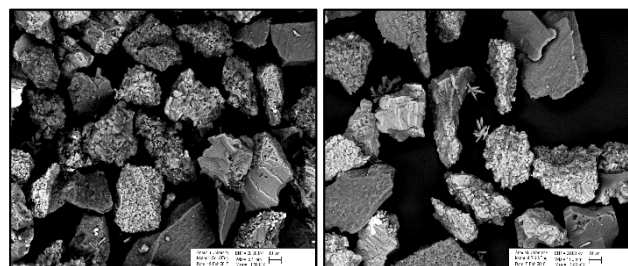


Figure 7. SEM Images of Wet (left) and Dry (right) Ground Samples from the -38+25 µm Fraction (Tokcan, 2017)

4.3. Effects of Grinding Conditions on Galenite Flotation Kinetics

The effect of different grinding conditions on the galenite flotation was determined by performing kinetic tests at the optimum conditions at which the highest recovery was obtained. Galenite rougher flotation concentrates were collected over time, and the data was analyzed based upon cumulative Pb recoveries and grades. Experimental conditions are presented in Table 3.

Table 3. Experimental Conditions for Galenite Flotation

	Reagents (g/t)	Dry Grinding	Wet Grinding
pH		8	8
Depressants	Na ₂ S ₂ O ₅	1000	1500
	NaCN	200	250
Collector	3418-A	30	60
Frother	AF-70	40	40

Figure 8 shows the variation of the cumulative Pb recovery with flotation time. While the highest recovery value was obtained at 20 µm grind size following dry grinding (DM-20) during the flotation period, the lowest recovery was obtained at 20 µm grind size following wet grinding (WM-20). Similar results were previously acquired at 50 µm grind size following dry (DM-50) and wet grinding (WM-50) conditions (Tokcan and Bozkurt, 2021). Higher recoveries were obtained after dry grinding at both grinding sizes. Even though minerals were expected to be more liberated at a 20 µm grind size, in contrast to dry grinding, slightly lower recovery values were acquired at the 20 µm size compared to the 50 µm size for wet grinding. The decrease in recovery could be attributed to the prolonged grinding time at 20 µm size. Recovery values for both in the case of different grinding conditions and particle sizes were quite similar at the end of the flotation.

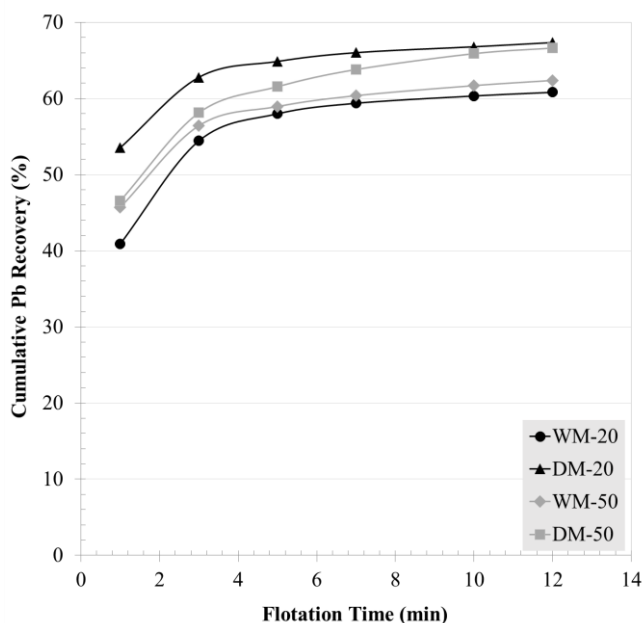


Figure 8. Cumulative Pb Recovery over Time

In studies with galenite mineral, it has been observed that the flotation kinetics are higher in autogenous and stainless-steel mills, that is, in more oxidizing environments, compared to reducing media such as steel mills (Learmont and Iwasaki, 1984, Rey and Formanek, 1960, Thornton, 1973, Cases, de Donato, Kongolo and Michot, 1989).

When the Pb grade over time is examined according to particle sizes, it is seen that in the case of dry grinding, lower grade values were acquired at 20 µm compared to wet grinding, while having higher grade values at 50 µm (Figure 9).

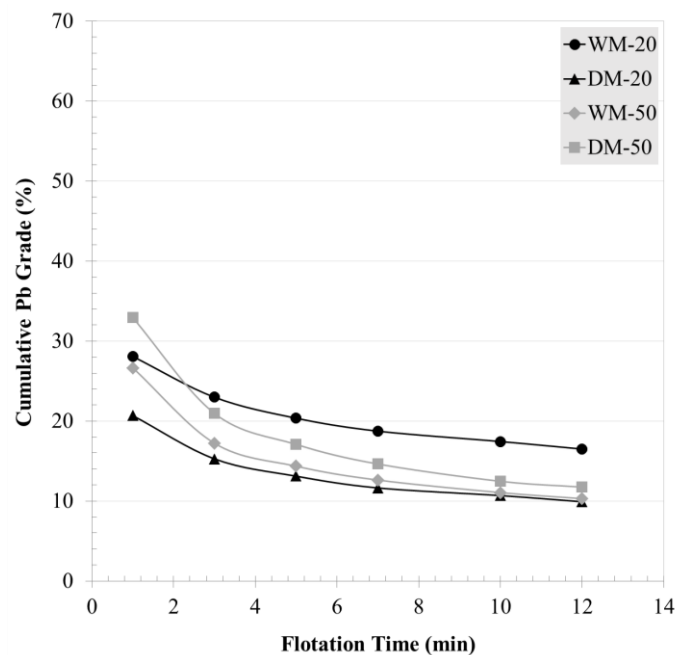


Figure 9. Cumulative Pb Grade over Time

The best results were obtained with the DM-50 sample in terms of both grade and recovery. Overall, it can be said that the dry grinding condition improved both Pb recovery and grade values at 50 µm compared to wet grinding, while having only higher Pb recoveries and lower Pb grades at 20 µm compared to wet grinding. This indicates that further grinding to 20 µm diminishes the flotation selectivity in dry grinding, perhaps due to the non-selective adsorption of fine particles on the mineral surfaces and causes a sudden decrease in the Pb grade values as the flotation time progresses, which is parallel with the highest Pb recoveries obtained at the same condition. Generally, it is also worth mentioning that better Pb grade values were obtained at 20 µm compared to 50 µm in wet grinding with similar Pb recoveries. This indicates that a 20 µm grind size has better flotation selectivity than a 50 µm grind size in wet grinding. Further grinding from 50 µm to 20 µm may be advantageous only in the case of wet grinding, possibly due to the improved dispersion conditions obtained in wet grinding, which protect the non-selective adsorption of fine particles onto mineral surfaces.

Figure 10 shows the flotation selectivity in the galenite flotation stage. In the case of dry grinding at both grind sizes, Zn recoveries in the Pb concentrate were quite high compared to wet grinding. This indicates that dry grinding resulted in the unintentional activation of sphalerite and hence selectivity loss in the galenite flotation. This could be attributed to the oxidizing environment provided during dry grinding (Seke and Pistorius, 2006; Chapman et al., 2013; Nooshabadi and Rao, 2014). It is also worth noting that selectivity loss,

i.e., sphalerite reporting to the Pb concentrate, was higher at 50 µm compared to 20 µm in both grinding conditions, despite similar Pb recoveries, indicating that further grinding to 20 µm resulted in relatively better selectivity compared to 50 µm.

The results indicate that the k values obtained at both grind sizes are higher for the dry grinding conditions compared to the wet grinding conditions, meaning faster flotation kinetics in the case of dry grinding. Furthermore, the higher rate constant values obtained at 20 µm compared to 50 µm grind size in the case of both grinding conditions imply faster flotation kinetics at 20 µm grind size. Furthermore, the kinetics of sphalerite reporting to Pb concentrate was also faster in the case of dry grinding and at 20 µm grind size.

4.4 Effects of Grinding Conditions on Sphalerite Flotation Kinetics

Experimental conditions for sphalerite rougher flotation kinetic tests are given in Table 5. The results of sphalerite flotation tests are shown in Figures 11 and 12.

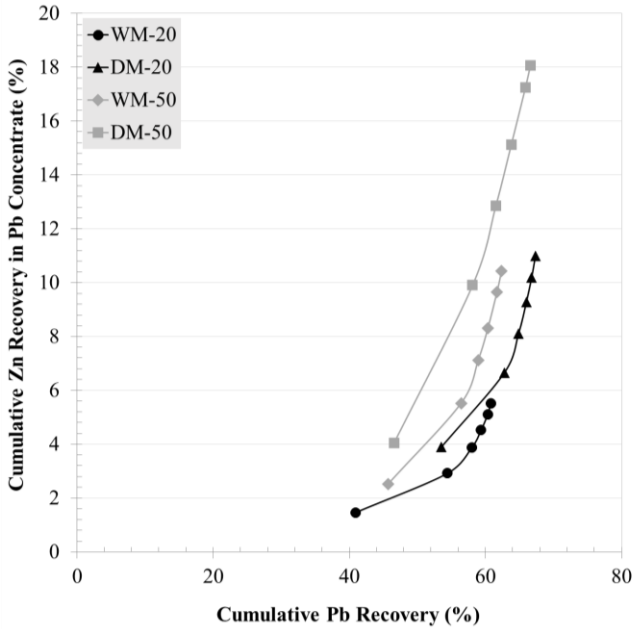


Figure 10. Cumulative Zn Recovery in Galenite Concentrate versus Cumulative Pb Recovery

In the galenite flotation stage, the flotation rate constants were also calculated to compare the effect of different grinding conditions based on a classical first-order flotation kinetics model (Equation 3).

$$R = R_{max} (1 - e^{-kt}) \tag{3}$$

where, R is the calculated recovery, R_{max} is the theoretical maximum recovery, k is the first-order flotation rate constant, and t is time. The results are presented in Table 4.

Table 4. First-Order Rate Constants of Galenite Flotation

		20 µm		50 µm	
		Pb	Zn in Pb	Pb	Zn in Pb
Rate constants, k	Dry grinding	1.66	0.38	1.31	0.27
	Wet grinding	1.13	0.26	1.25	0.22

Table 5. Experimental Conditions for Sphalerite Flotation

Reagents		Dry & Wet Grinding Samples
pH		11
Activator	CuSO ₄ (g/t)	1250
Collector	SIPX (g/t)	60
Frother	AF-70 (g/t)	40

Figure 11 shows the variation of the cumulative Zn recovery over flotation time. The Zn recoveries obtained in the first five minutes appear to be quite high, indicating that the majority of the sphalerite was recovered within the first five minutes, except for dry grinding at 50 µm. The highest Zn recoveries were obtained in the case of dry grinding at 20 µm grind size, while the lowest Zn recoveries were at 50 µm with dry grinding for all other conditions ultimate zinc recoveries are same. This is parallel with the results of the highest Zn recoveries reported to the Pb concentrate (Figure 10). In the case of wet grinding, Zn recoveries were low at shorter flotation times but increased at both grind sizes, particularly at longer flotation times. The Zn recovery differences in different grinding conditions got smaller and became quite similar at longer flotation times. As a result, in the case of sphalerite flotation, the enhanced flotation response of sphalerite observed after dry grinding may have been diminished due to the longer exposure time of sphalerite surfaces to water.

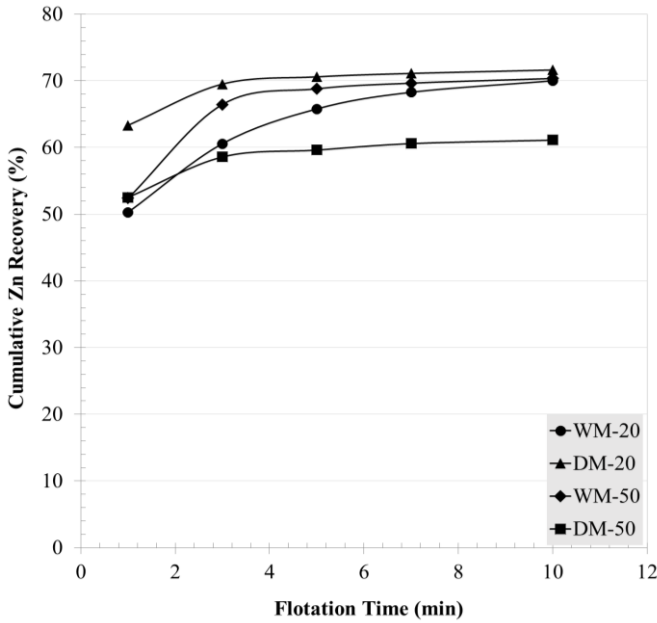


Figure 11. Cumulative Zn Recovery over Time

The variation of the cumulative Zn grade with flotation time is depicted in Figure 12. The lowest Zn grades were acquired at a 50 µm grind size in the case of dry grinding, in accordance with the obtained Zn recoveries under the same conditions. The highest grade values obtained at the grind size of 20 µm with similar Zn recoveries could be attributed to the better liberation of the sphalerite compared to 50 µm.

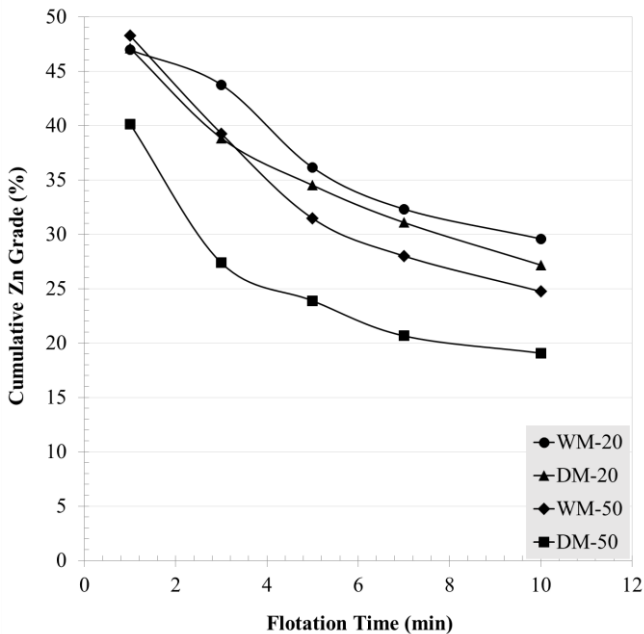


Figure 12. Cumulative Zn Grade over Time

Calculated first-order flotation rate constants are presented in Table 6. The k values obtained at both grind sizes are higher for the dry grinding conditions compared to the wet grinding conditions, meaning faster flotation kinetics in the case of dry grinding. Furthermore, the rate constant values obtained at both grind sizes are quite similar in the case of dry and wet grinding conditions.

Table 6. First-Order Rate Constants of Sphalerite Flotation Stage

		20 µm	50 µm
		Zn	Zn
Rate constants, k	Dry grinding	2.11	2.07
	Wet grinding	1.10	1.40

4.4. Effects of Grinding Conditions on the Pulp Chemistry

In flotation, pulp chemistry, especially in terms of E_h interactions between minerals and minerals and the grinding medium, plays a vital role. Pulp potential (E_h), an indication of the pulp chemistry, is a critical monitoring tool and control parameter affecting the success of the flotation process. E_h is used as an indicator in oxidation-reduction environments and is affected by the pulp's pH and dissolved oxygen amounts. It is known that E_h values are directly dependent on grinding conditions. Thus, grinding conditions play an essential role in sulfide minerals' flotation recovery and selectivity.

The change in E_h values during flotation stages was monitored over time following dry and wet grinding. The monitored E_h values are shown in Figure 13. The E_h values of the dry grinding samples are very close to each other, while the pulp potentials are significantly reduced after wet grinding. There is a potential difference of around 350 mV between the dry-ground and wet-ground samples. Due to the longer grinding time, this difference becomes even more remarkable at a 20 µm grind size. High pulp potential values of dry ground samples show superior flotation performance compared to wet grinding at both particle sizes studied, especially in the galenite flotation stage, bearing in mind that sphalerite reporting to galenite concentrate was increased as well. In the literature, it has been shown that dry grinding prior to flotation may have advantages over wet grinding, particularly in sulfide ores. In a dry grinding environment, the newly liberated mineral surfaces are not affected by galvanic interactions during grinding and are affected much less during the following flotation process. Hence, better flotation responses were observed after dry grinding compared to wet grinding.

In the case of the following sphalerite stage, the enhanced flotation response of sphalerite observed after dry grinding was diminished since the E_h difference observed in the case of dry and wet grinding conditions was minimized along with the longer exposure time of sphalerite surfaces to water. Similar results were observed in the literature and attributed to the rapid oxygen consumption in the steel grinding medium, which is generally electrochemically active. The E_h and dissolved oxygen values decrease, and a reducing environment is formed. The problem with the reduction in pulp potential values is usually related to preventing thiol collectors' adsorption to the surface of the sulfide minerals and resulting in the inhibition of flotation (Forssberg et al., 1993; Leppinen et al., 1998; Martin et al., 1992; Yuan et al., 1996a, b). The low potential values observed after wet grinding also indicate the presence of oxygen consumers, such as metallic iron, in the pulp (Bruckard et al., 2011). The observed low potential and dissolved oxygen ratios cause a decrease in the oxidation of minerals during the conditioning phase (Koleini et al., 2012). Due to the lower pulp potential of the steel grinding medium, iron hydroxide products are formed in the pulp, and as discussed earlier, these formed species may have adversely affected the galenite-sphalerite flotation. This difference in pulp potentials after dry and wet grinding shows how the products form as a result of galvanic interaction during wet grinding and affect the pulp chemistry and floatability of the ore.

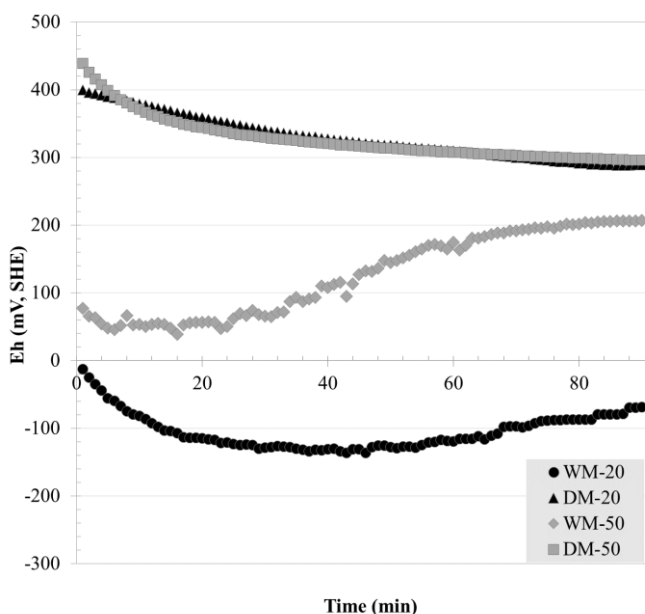


Figure 13. Pulp Potential and Time Relationship

5. Conclusions

Particle size analysis, together with the particle shape

and morphology characterization tests performed on the Pb-Zn complex sulfide ore, revealed that the difference between the samples utilized in the kinetic flotation test was negligible; therefore, the difference in flotation response of the ore might be due only to pulp chemistry differences generated by the dry and wet grinding conditions. Overall, kinetic flotation tests showed a significant difference between the flotation performances of the ore following dry and wet grinding conditions.

In the galenite flotation stage, higher Pb-recoveries were obtained at 50 and 20 μm grind sizes following dry grinding compared to wet grinding, but with a significant loss in selectivity due to the unintentional activation of sphalerite. This was attributed to the significantly higher positive pulp potentials, i.e., the highly oxidizing environment provided during dry grinding. Calculated flotation rate constants at 50 and 20 μm in the case of dry and wet grinding conditions also further confirmed these results.

In the sphalerite flotation stage, the highest Zn recoveries were obtained in the case of dry grinding at 20 μm grind size, while the lowest Zn recoveries were at 50 μm due to the highest Zn recoveries reported to the Pb concentrate. The Zn recovery differences following dry and wet grinding conditions were quite similar, indicating that the enhanced flotation response of sphalerite observed after dry grinding may have been diminished due to the longer exposure time of sphalerite surfaces to water, as confirmed by the measured E_h values. The highest Zn grade values obtained at the grind size of 20 μm were attributed to the better liberation of the sphalerite. Calculated flotation rate constants at 50 and 20 μm in the case of dry and wet grinding conditions were also in accord with the results.

This study showed that differences in grinding schemes in terms of dry and wet grinding affect flotation performance significantly and necessitate an elaborate reagent regime with strict control of pulp Eh and pH.

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Author Contributions

Işıl Tokcan contributed to the implementation of the research, analysis of the results, and writing of the manuscript. Murat Mümtaz Volkan Bozkurt contributed to the design of the research, analysis, and discussion of the results and review of the manuscript.

Conflict of Interest

No conflict of interest was declared by the authors.

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EX VIVO MICROWAVE ABLATION APPLICATION AT 2.45 GHz BY A NOVEL NITI SHAPE MEMORY ALLOY BASED RING ANTENNA

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Keywords	Abstract
<p>Microwave ablation Ring antenna Ex vivo NiTi (nickel titanium)</p>	<p>Although the most preferred treatment methods in cancer treatment are still surgery and chemotherapy, microwave ablation, one of the minimally invasive thermal ablation techniques, is increasingly used in the clinic for patients who cannot afford the risks of these treatment methods. In this study, microwave ablation with a new NiTi ring antenna was performed on a freshly slaughtered beef liver as an Ex Vivo application. Design and optimization was carried out in the CST Microwave studio. Ex Vivo MWA application was carried out at 2.45 GHz, using 50 W microwave power for 5 minutes. The lowest width of the ablation zone formed along the x-axis was 14.58 mm, the highest width was 28.61 mm, the length of the ablation area along the y-axis was 58.032 mm, and the area of the ablation zone was approximately 5.44 cm². These results show that the proposed NiTi ring antenna has the ability to achieve a sufficient thermal lesion in terms of ablation zone dimensions.</p>

YENİ BİR NİTİ ŞEKİL HAFIZALI ALAŞIM TABANLI HALKA ANTEN İLE 2.45 GHz'DE EX VIVO MİKRODALGA ABLASYON UYGULAMASI

Anahtar Kelimeler	Öz
<p>Mikrodalga ablasyon Halka anten Ex vivo NiTi (nikel titanyum)</p>	<p>Kanser tedavisinde en çok tercih edilen tedavi yöntemleri hala cerrahi ameliyat ve kemoterapi olsa da, bu tedavi yöntemlerindeki riskleri kaldıramayacak hastalarda, minimal invaziv termal ablasyon tekniklerinden biri olan mikrodalga ablasyon uygulaması gittikçe artan bir oranda klinikte kullanılmaktadır. Bu çalışmada, Ex Vivo uygulaması olarak yeni kesilmiş bir sığır karaciğerine yeni bir NiTi halka anten ile mikrodalga ablasyon uygulaması gerçekleştirilmiştir. Tasarım ve optimizasyon CST Mikrodalga stüdyoda gerçekleştirilmiştir. Ex Vivo MWA uygulaması, 2.45 GHz' de, 50 W mikrodalga gücünün 5 dakika süresince kullanılmasıyla gerçekleştirilmiştir. x eksenini boyunca oluşturulan ablasyon bölgesinin en düşük genişliği 14,58 mm, en yüksek genişliği 28,61 mm, y eksenini boyunca elde edilen ablasyon alanının uzunluğu 58.032 mm ve ablasyon bölgesi alanı ise yaklaşık 5.44 cm² olarak elde edilmiştir. Elde edilen bu sonuçlar önerilen NiTi halka antenin ablasyon bölgesi boyutları açısından yeterli bir termal lezyonu başarma kabiliyetine sahip olduğunu göstermektedir.</p>

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1. Introduction

Liver cancer is the second most common type of cancer in cancer-related deaths in the world, and surgical

treatment methods such as resection and transplantation have become standard among possible treatment methods, especially for early-stage Hepatocellular Carcinoma (HCC). However, it has also been noted that surgical resection is not possible in



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more than 75% of patients with liver cancer (Liu, Zhang, and Jiang, 2003; Torre, Siegel, Ward, and Jemal, 2016). The thermal therapy commonly used to treat hepatic cancer include radiofrequency ablation, cryoablation, and microwave ablation. Radiofrequency ablation has disadvantages such as high impedance between the electrode and the ground plate as a result of the blood vessel making the ablation temperatures too low to completely destroy cancer cells and the increase in tissue temperature during application if the targeted area is adjacent to a high flow blood vessel. In addition, the diameter of the tissue coagulated by the RF electrodes is limited to 1.6 cm. This is because the higher energy to achieve larger coagulation diameters causes charring of the tissue near the electrode. This increases local tissue impedance, reduces RF accumulation, heat diffusion, and coagulation necrosis (Goldberg et al., 1998; Lencioni et al., 1998; Goldberg et al., 1995). Cryoablation (CA), which uses cold compressed argon gas to destroy cancer tissue, has advantages such as minimal damage to large vessels, low incidence of pain and controllable ice sphere formation. However, in addition to these advantages, it also has important disadvantages such as the ablation area being limited to the small areas surrounding the cryoablation needles and the possibility of damaging the phrenic nerve (Liu et al., 2020; Seifert, Junginger, and Morris, 1998; Phasukkit, and Wongketsada, 2021). MWA is a thermal therapy used in the treatment of tumors in various tissue types such as liver, lung, breast, kidney and bone. In this therapy, electromagnetic energy is directed to the tumor for a few minutes with an interstitial antenna, in order, EM power is absorbed by the tumor tissue, and the absorbed power heats the tumor tissue, and when the temperature reaches stotoxic levels, between 60°C and 100°C, coagulation necrosis occurs on the tissue. In antenna design, the lowest possible return loss is desired for maximum energy transfer to the tissue. The frequency used is generally 915 MHz and 2.45 GHz. Since the majority of hepatic tumors such as liver tumors and lung tumors are spherical, it is preferred that the ablation pattern of the antenna to be used is approximately spherical (Mohtashami, Hagness, and Behdad, 2017; Yang et al., 2006; Yang, Converse, Mahvi, and Webster, 2007; Luyen, Hagness, and Behdad, 2017; Liu et al., 2016; Etoz, and Brace, 2018; Ahmed, Brace, Lee, and Goldberg, 2011; Luyen, Hagness, and Behdad, 2015; Hodgson et al., 1999; Prakash, 2010). Therefore, in our study, it was preferred to use an antenna type with an approximately spherical ablation pattern.

MWA has some advantages over other thermal treatment methods. Advantages such as low cost, simultaneous use with multiple applicators, shorter ablation time, larger ablation area due to blood perfusion, lower infection risk, lower recovery time, ability to cause necrosis in deeply located tumors, and

very lower cancer recurrence can be counted among these (Wright, Lee, and Mahvi, 2003; Andreano, Huang, Meloni, Lee, and Brace, 2010; Wright et al., 2005; Lubner, Brace, Hinshaw, and Lee, 2010; Hancock, 2011; Hassan, Takruri, and Hope, 2016; Hubner et al., 2019; Reimann et al., 2019; Shock et al., 2004). MWA is stronger than other thermal ablation methods in organs with high blood perfusion such as the liver, so it is frequently used in the treatment of liver cancer (Brace, 2020). In the literature, various antennas such as slot, monopole, dual slot, multi slot, dipole, choke dipole, triaxial, helical, floating sleeve and loop antennas have been used for microwave heating (Mohtashami, Hagness, and Behdad, 2017; Yang et al., 2006; Luyen, Hagness, and Behdad, 2015; Brace, 2011; Ge et al., 2018; Hurter, Reinbold, and Lorenz, 1991; Mohtashami et al., 2018; Brace, Laeseke, Van der Weide, and Lee, 2005; Sugiyama, Saito, 2018). With its simple geometry, circular loop antennas are preferred in many application areas, especially near field communication and RFID applications. For a circular loop carrying a uniform current, near-field expressions such as simple and precise fields and areas along the loop axis can be generated from full general field expressions as special cases, while far fields for a circular loop antenna on the ground plane can be derived from general field expressions (Hamed et al., 2014). Loop antennas are also used in intracranial pressure monitoring, which provides detailed information about the brain, blood and cerebrospinal fluid (Tamilarasan, Krishnadhas, Sabapathy, and Sarasa, 2021). Loop antennas are classified as circular, rectangular and square in shape, and electrically classified as small antennas and large antennas. While the design time, limited bandwidth, antenna size and difficulties in radiation efficiency are the parts that need to be studied, while it is easy and low cost to construct, simple, and an omnidirectional antenna for many important applications. In addition, it is less affected by environmental noise as it does not need ground plane (Ako et al., 2019; Bolton, 2016). The human body decreases the electric field and increases the magnetic field because its conductivity is low. This led to the idea that electrically small (loop's circumference $< 0.3 \lambda$) magnetic loop antennas are the most efficient antennas for wearable miniature equipment such as pagers and RF tags (Niekerk et al., 2002; Fujimoto, and James, 2001). If the circumference of a loop antenna is smaller than the wavelength, there is a problem of matching the radiation resistance with a 50 ohm transmission line (Balanis, 1982). The SAR pattern is one of the most important parameters for MWA and shows the energy absorbed by the tissue, in other words, the heating ability of the MWA system. In addition, the shape of the ablation zone is also highly dependent on the SAR distribution.

In this study, Ex Vivo MWA application was performed on a freshly cut beef liver using a NiTi shape memory alloy-based ring antenna produced by us and presented in our previous study (Gorgun, Çomlekci, and Kaya, 2019), using 50 W microwave power at 2.45 GHz for 5 minutes, and the relevant results are presented.

2. Method

2.1. SMA (Shape Memory Alloy) Material

NiTi alloys are frequently used in biomedical surgical devices and biomedical applications due to their features such as superior corrosion resistance, biocompatibility, magnetic resonance, computed tomography compatibility, especially with minimally invasive surgery, which is one of the most important advances in the field of modern medicine (Fadlallah, El-Bagoury, Gad, Ahmed, and El-Ousamii, 2014; Morgan, 2004; Holton, Walsh, Anayiotos, Pohost, and Venugopalan, 2002; Song, 2010).

2.2. Method of Antenna Preparation

In the realization of novel and NiTi SMA based ring antenna, coaxial cable is also used together with NiTi SMA wire. The characteristics of this coaxial cable used are presented in Table 1.

Table 1. Coaxial Cable Specifications

	Material	Diameter
Inner Conductor	StCu, Silver plated	0.53 mm
Dielectric	PTFE (polytetrafluorethylene)	1.65 mm
Cable Sheath	Braid + Band copper, tin plated	2.10 mm

The CST drawing of the NiTi ring antenna is presented in Figure 1.

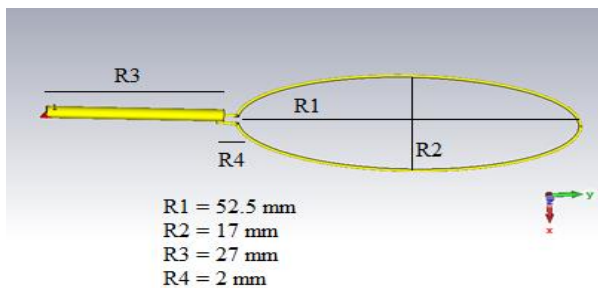


Figure 1. Dimensions and CST Drawing of NiTi Ring Antenna

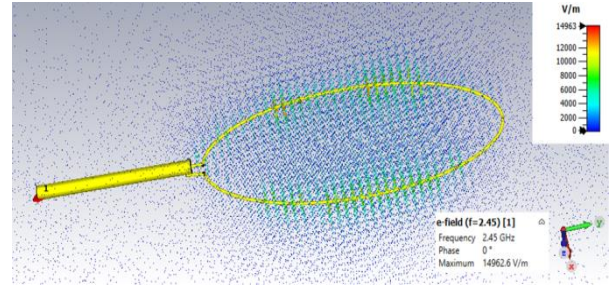


Figure 2. E-Field

As shown in Figure 2, the maximum electric field value 2.45 GHz at 14963 (V / m).

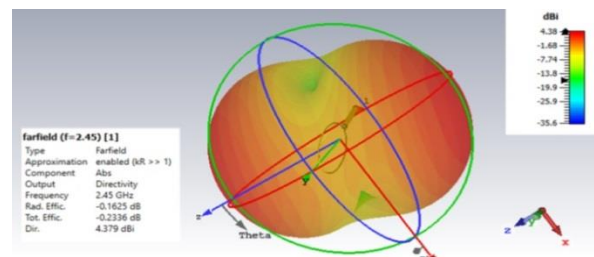


Figure 3. Directivity

As shown in Figure 3, the directivity was 4.38 dBi at 2.45 GHz.

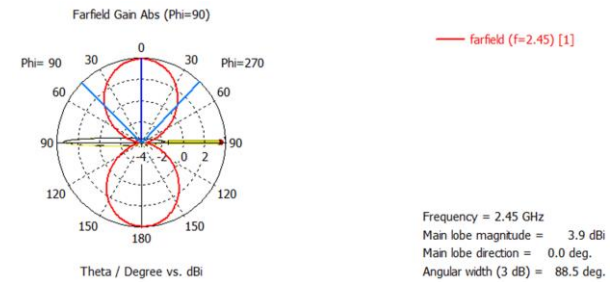
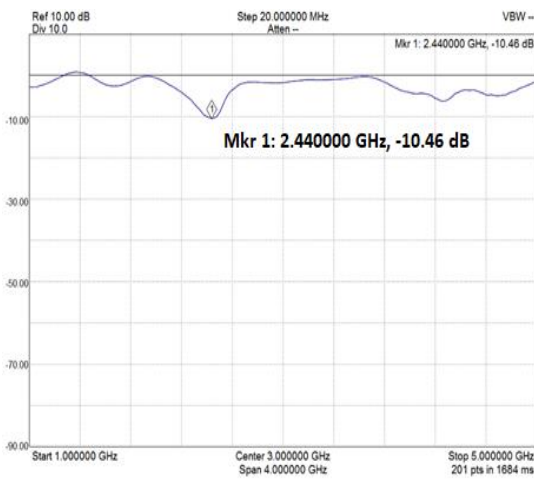


Figure 4. Farfield Gain Abs (Phi=90)

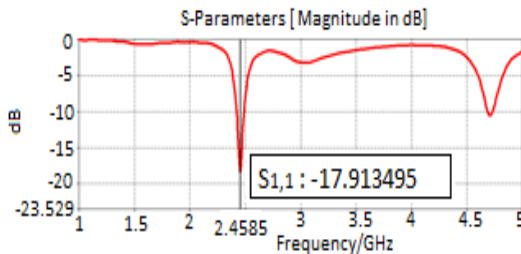
Farfield gain abs (Phi=90) is presented in Figure 4 at 2.45 GHz.



(a)



(b)



(c)

Figure 5. a) NiTi Ring Antenna b) Return loss (S_{11}) measurement of NiTi ring antenna at 2.44 GHz. c) Return loss (S_{11}) simulation of NiTi ring antenna at 2.45 GHz.

As seen in Figure 5.b, return loss of proposed antenna was measured as -10.46 dB at 2.44 GHz. And as seen in Figure 5.c, return loss of proposed antenna was simulated as -17.91 dB at 2.45 GHz.

Especially since the 0.5 mm diameter NiTi SMA wire added to the end of the coaxial cable is a hard material, it could not be made into a full ellipse as in the simulated image of the antenna. This is the most important reason for the difference between the above simulation and measurement S_{11} results.

2.3. Circle Shape NiTi Wire Preparation Process

A novel and NiTi SMA-based ring antenna was realized by adding 0.5 mm diameter NiTi wire to the end of the 27 mm long coaxial cable, one end to the inner conductor of the coaxial cable and the other end to the outer conductor, adding an elliptical ring with a diameter of 17 mm and a long diameter of 52.5 mm.

2.4. Mathematical Descriptions of the Simulation Models

The dimensions of the model components are given in Table 2.

Table 1. Dimensions of Model Components

Components	Dimensions	
	Length (mm)	Diameter (mm)
Inner Conductor	27	0.51
Dielectric	27	1.68
Outer conductor	27	2.20
Catheter	27	2.40
Components	Dimensions	
	Diameter of NiTi wire (mm)	Short diameter/ Long diameter of the ellipse (mm)
NiTi Ring Antenna	0.5	17.0/ 52.5

2.5. Temperature Analysis Procedure

The bioheat transfer equation used to obtain the temperature distribution of the living tissue is shown in equation (1).

$$\rho c \frac{\partial T}{\partial t} = k \nabla^2 T - \rho \rho_b c_b F (T - T_b) + Q \tag{1}$$

where ρ is the tissue density ($kg.m^{-3}$), c is the specific heat capacity of the tissue ($J.kg^{-1}.K^{-1}$), T is the temperature, t is the heat transfer time, k is the thermal conductivity ($W.m^{-1}.K^{-1}$), ρ_b is the blood density ($kg.m^{-3}$), c_b is the specific heat capacity of the blood ($J.kg^{-1}.K^{-1}$), F is the blood flow rate ($m^3.kg^{-1}.s^{-1}$), T_b is the temperature of the blood, and Q is the energy deposited by the antenna into the tissue ($W.m^{-3}$).

$$\omega_b = \rho F \quad (s^{-1}) \tag{2}$$

where ω_b is the blood perfusion rate, ρ is the tissue density ($kg.m^{-3}$), and F is the blood flow rate ($m^3.kg^{-1}.s^{-1}$).

$$Q = \sigma|E|^2 = \rho SAR = J.E \quad (W.m^{-3}) \quad (3)$$

Where Q is the energy deposited by the antenna into the tissue ($W.m^{-3}$), σ is the tissue conductivity ($S.m^{-1}$), ρ is the tissue density ($kg.m^{-3}$), E is the applied electric field ($V.m^{-1}$), SAR is the specific absorption rate ($W.kg^{-1}$), and J is the current density ($A.m^{-2}$).

Equation 4 is obtained by putting the equations 2 and 3 in their places in the equation 13.

$$\rho c \frac{\partial T}{\partial t} = k \nabla^2 T - \rho_b c_b \omega_b (T - T_b) + \rho SAR \quad (4)$$

In Ex Vivo applications, $\omega_b = 0$ is taken as there is no perfusion.

The initial temperatures of the tissue, blood, and air are all 37 °C. Thermal constants are shown in Table 3.

Table 3. Electromagnetic properties at 2.45 GHz and Thermal Properties of liver Tissue (Kaur, and Maini, 2014; Dielectric Properties of Body Tissues, 2021)

Properties	Value
Thermal conductivity, liver (k) [W/mK]	0.56
Specific heat capacity, blood (c_b) [J/kgK]	3639
Specific heat capacity, liver (c) [J/kgK]	3600
Density, blood (ρ_b) [kg/m^3]	1000
Density, liver (ρ) [kg/m^3]	1020
Blood perfusion rate [$1/s$]	.0036
Blood temperature [$degC$]	37.00
Relative permittivity, liver (ϵ_r)	43.03
Electric conductivity, liver (σ) [S/m]	1.69
Relative permittivity, dielectric	2.03
Relative permittivity, catheter	2.60

2.6. Microwave Ablation

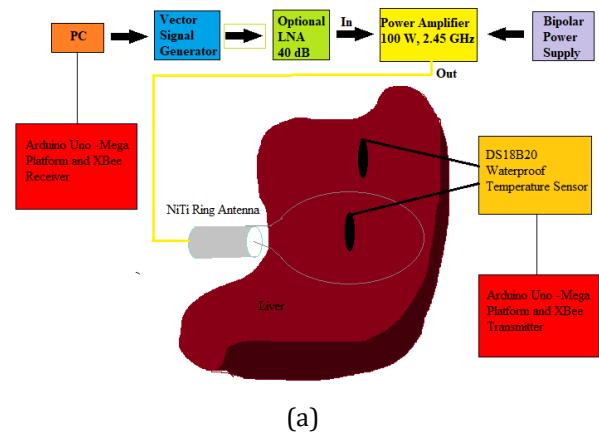
MWA is a safe minimally invasive treatment method, which is among the thermal therapy methods and applied in cancer treatments. This method is usually performed at ISM frequencies of 915 MHz or 2.45 GHz. In MWA application, the electromagnetic waves produced are directed to the tumor tissue by means of a suitable antenna. As a result of the absorption of the power produced by the electromagnetic wave by the tissue, the polar water molecules in the tissue begin to

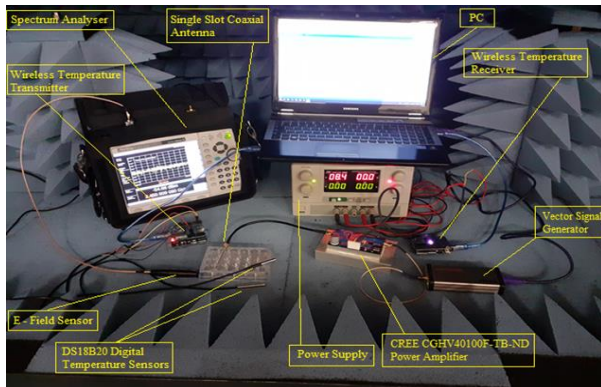
oscillate rapidly with this magnetic field. For this reason, as a result of the frictional heat generated, the ablation area heats up and cell death occurs when the temperature exceeds 60 degrees, which causes necrosis of tumor cells. The dielectric permeability and conductivity of the tissue are also very important parameters in the absorption of electromagnetic power by the tissue. In particular, the amount of power applied, the specific absorption rate, the rate of blood perfusion, the ablation time, the thermal properties of the environment, the MWA antenna type and diameter used, the size of the ablation zone and the maximum temperature level reached (Seki et al., 1994; Liang, Wang, 2007; O'Rourke et al., 2007; Nan et al., 2013).

The assumption that the targets to be treated are spherical in shape and that there is isotropic energy dissipation can generally be met for tumors smaller than 2.5 cm. Therefore, heating large areas deviates from the ideal ablation model due to the heterogeneous nature of tissue properties over 2.5 cm. It is necessary to pay attention to the optimum ablation time in order to obtain a situation in which MWA application will cause the least damage to the surrounding healthy tissues.

2.7. System Concept

VSGA25 as vector signal generator used. The VSGA25 provided the system with a 2.45 GHz continuous sine wave with 0 dBm output, 1kHz simulation rate and 50% depth. Its 0 dBm output is amplified by a 2.45 GHz, 100W CGHV40100F power amplifier powered by a DC power supply. NiTi Ring antenna is connected to the output of the power amplifier. During the MWA application, the temperature was monitored by Xbee & Arduino-based wireless data transfer using DSD18B20 sensors. The MWA application setup diagram and the pictures of the realized MWA application setup are given in Figure 6.





(b)

Figure 6. a)MWA Application Setup Block Diagram b) Realized MWA Application Setup with NiTi Ring Antenna at 2.45 GHz.

In this study, as a power amplifier, the CREE CGHV40100F-TB-ND of Cree is utilized which hosts an unmatched, GaN HEMT. The image of CGHV40100F-ND GaN HEMT power transistor, and the circuit diagram of the power amplifier are given in Figure 6.

3. Results

3.1. MWA Application at 2.45 GHz on Freshly Cut Beef Liver with NiTi Ring Antenna

For different input values at 2.45 GHz, forward power, and reverse power values are given in Table 4.

Table 4. Forward Power, and Reverse Power Values for Different Input Value at 2.45 GHz

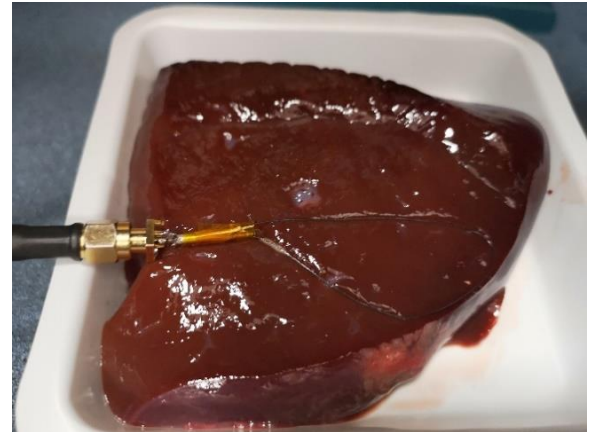
Frequency	VGSA Vector Signal Generator (AM modulated sine wave) Amplitude	Forward Power	Reverse Power
2.45 GHz	-20 dBm	32.35 dBm	19.79 dBm
2.45 GHz	-10 dBm	43.37 dBm	27.37 dBm
2.45 GHz	0 dBm	47.92 dBm	35.18 dBm

In Signal Hound VSGA25 100 MHz - 2.5 GHz Vector Signal Generator which will last 100 W, 2.4 GHz - 2.5 GHz PA according to Figure 7, the frequency was set to 2.45 GHz, amplitude was set to 0 dBm and modulation type was set to AM ((Modulation speed: 1 kHz, Modulation depth: 50%, Modulation format: Sine Wave) and driven. The VGS25A Vector Signal Generator in MWA setup was applied to our sine wave antenna

with an amplitude of 0 dBm, 47.92 dBm (about 50 W) AM at 2.45 GHz. The relationship between temperature obtained by thermal camera and application time is presented below.

3.2. MWA Implementation Results Performed with NiTi Ring Antenna at 2.45 GHz

Liver images obtained depending on the durations of application are presented in Figure 8.



(a)



(b)



(c)



(d)

Figure 7. Liver Images Obtained Depending on the Durations of Application (t) in MWA Application Performed, a) t = 0, b) t = 1 min, c) t = 3 min, d) t = 4.5 min

Figure 7. (a) of freshly cut beef liver before MWA application, Figure 7. (b), Figure 7. (c), and Figure 7. (d). MWA application is the 1st min end view, 3rd min end view and the view at the end of 4 and a half minutes, respectively.



(b)



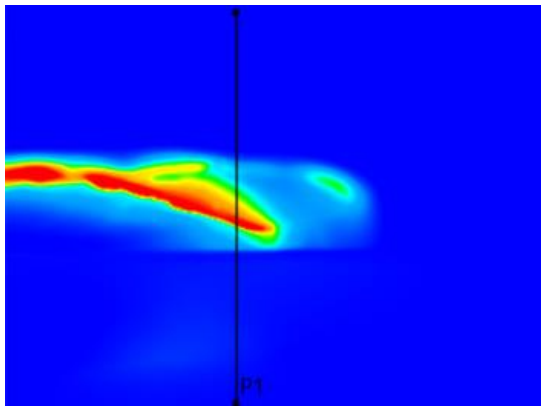
(c)

Figure 8. Dimensions of Ablation, a) Vertical Section Minimum Ablation Zone Size, b) Vertical Section Maximum Ablation Zone Size and c) Horizontal Section Maximum Ablation Zone Size.

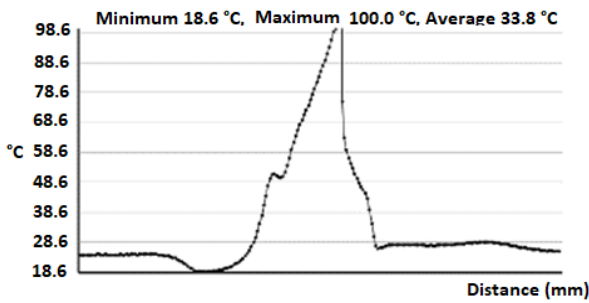


(a)

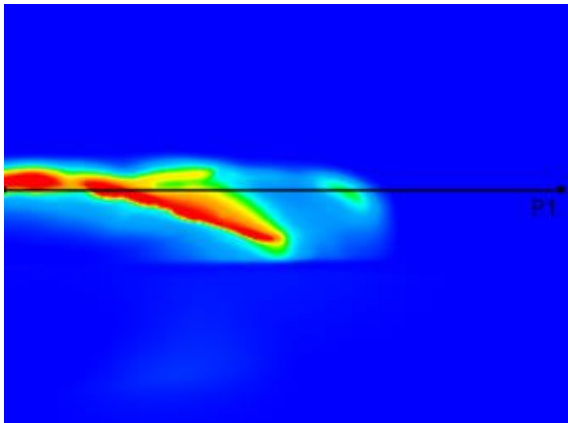
At the end of the 5th minute, ablation regions formed in freshly cut beef liver are shown in Figure 8. (a) Figure 8. (b) and Figure 8. (c). As seen in Figure 8. (c), the lowest width of the ablation zone formed along the x axis is 14.58 mm, as seen in Figure 8. (b), the highest width of the ablation zone formed along the x axis is 28.61 mm and As can be seen in Figure 8. (c), the length of the ablation area obtained along the y axis was measured as 58.032 mm after 5 minutes of microwave ablation application with 50 W power.



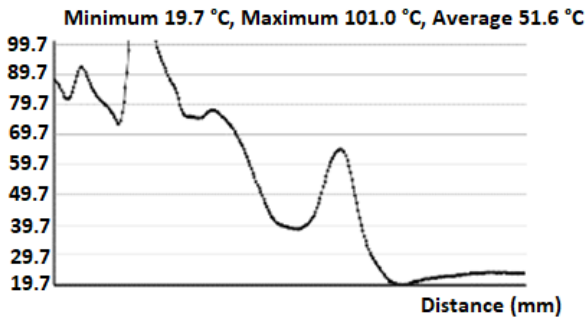
(a)



(b)



(c)



(d)

Figure 9. a) Thermal Camera Image Vertical Section Axis, b) Temperature Distance Relationship along the Vertical Axis Line, c) Thermal Camera Image Horizontal

Section Axis, d) Temperature Distance Relationship along the Horizontal Axis Line

According to the temperature distance graph obtained along the vertical axis line in Figure 9. (b), it is observed that a minimum of 18, 6 °C, maximum 100 °C in the regions seen in red and average 33.8 °C temperatures are reached.

According to the temperature distance graph obtained along the vertical axis line in Figure 9. (d), it is seen that minimum 18.7 °C, maximum 101 °C in the regions seen in red and average 51.6 °C temperatures are reached.

Looking at the literature, coaxial slot antennas are frequently used in cancer treatments with MWA. Some of the similar studies in the literature (Ibitoye et al., 2015; Yang et al., 2006; Amabile et al., 2017) and our study are presented in Table 5 comparatively. The originality of our study is that it is a ring antenna based on NiTi shape Memory alloy and the resultant approximate ellipsoid ablation area is comparable to the studies in the literature in terms of ablation length, ablation diameter and ablation zone area. It is thought to be a usable antenna, especially in large-scale skin tumors. The comparison of this study with similar studies in the literature is presented in Table 5.

Table 5. The Comparison of This Study with Similar Studies in the Literature

Antenna Type	Input power/ Ablation duration	Ablation length/ Ablation diameter	Ablation zone shape	Ref
Dual slot antenna	50 W/ 5 Min	44.3± 0.4 mm / 34.4± 0.6 mm	ellipsoid	(Ibitoye et al., 2015)
metallic sleeve antenna	120 W/ 2.5 Min	5.87± 0.32cm / 3.64± 0.33 cm.	ellipsoid	(Yang et al., 2006)
Floating sleeve antenna	60 W / 5 Min	4.8 ± 0.2 cm / 3.4 ± 0.3 cm	ellipsoid	(Amabile et al., 2017)
Miniaturized sleeve choke coaxial antenna	50 W/ 5 Min	58.03 ± 0.2 mm / 21.59 ± 0.1 mm	ellipsoid	This work

In terms of the obtained ablation zone diameter and the horizontal and vertical maximum lengths of the ablation zone, results close to the studies in the literature were obtained.

4. Conclusions

MWA applications are generally used as a minimally invasive method in liver and lung tumors as an alternative to treatment options such as chemotherapy and surgical applications, especially in elderly or severe patients who cannot undergo surgery. In liver and lung tumors, which are generally spherical, it is necessary to heat the tumor to 60 centigrade degrees, where coagulation will occur, by heating the tumor with the noninvasive or minimally invasive MWA application in a short period of 3-5 minutes, thus rendering the tumor ineffective. In addition, in order to reduce the invasiveness of all these, it is necessary to apply high Watt to the tumor tissue, to raise the relevant tissue above 60 centigrade in a short time, to perform the MWA application with an antenna with a spherical radiation pattern, since the tumor is spherical, and to obtain a wider ablation area for tumors larger than 2.5 cm. Again, in addition to the high directivity of the antenna, the fact that it is designed from a material with high biocompatibility and corrosion resistance at high temperatures is due to all these requirements.

Designed NiTi ring antenna by adding NiTi wire to the end of the coaxial cable is an MWA antenna that can be used especially in wide cancer region. Computational results were obtained with MWA application in ex vivo bovine liver at 2.45 GHz, by using 50 W microwave power for 5 minutes. Results show that it is obtained the lowest width of the ablation zone formed along the x axis is 14.58 mm, the highest width of the ablation zone formed along the x axis is 28.61 mm, the length of the ablation area obtained along the y axis was measured as 58.032 mm and about 5.44 cm² area of ablation zone. According to the temperature distance graph obtained along the vertical axis line in Figure 6.(b), it is observed that a minimum of 18,6 °C, maximum 100 °C in the regions seen in red and average 33,8 °C temperatures are reached. According to the temperature distance graph obtained along the vertical axis line in Figure 6.(d), it is seen that minimum 19.7 °C, maximum 101 °C in the regions seen in red and average 51.6 °C temperatures are reached. In terms of the obtained ablation zone diameter and the horizontal and vertical maximum lengths of the ablation zone, results close to the studies in the literature were obtained.

Contribution of Researchers

In the study carried out, Ahmet Rifat GÖRGÜN contributed in the titles of literature review, procurement of materials used, simulation, design and spelling. Adnan KAYA contributed to the formation of ideas, evaluation of the results obtained, and analysis of the results. Selçuk ÇÖMLEKÇİ, on the other hand, contributed to the control of the article in terms of content.

Conflict of Interest

There is no conflict of interest with any person/institution in the prepared article.

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ÖĞRENCİ-PROJE ATAMA PROBLEMİNDE FARKLI GRUP KARARLARININ DEĞERLENDİRİLMESİ

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Anahtar Kelimeler	Öz
<p>Öğrenci-Proje Atama (ÖPA) Grup Kararı Matematiksel Programlama Tamsayılı Programlama Hedef Programlama</p>	<p>Öğrenci-Proje Atama (ÖPA), genel olarak, çeşitli kriterlerin dikkate alınmasıyla öğrenci-proje gruplarının oluşturmasını ve bu gruplara projelerin atanmasını içeren çok-kriterli bir problem olarak tanımlanabilir. Bu çalışmada, problemin çözümü için üç aşamadan oluşan bir yaklaşım önerilmektedir. Yakın tarihli başka bir çalışmada geliştirilmiş olan bir 0-1 tamsayılı-hedef programlama formülasyonundan adapte edilmiş olan matematiksel programlama modeliyle, çalışmanın ilk aşamasında çeşitli kriterler dikkate alınarak öğrenci-proje gruplarının oluşturulması gerçekleştirilmektedir. Söz konusu kriterler ise (i) bir gruptaki öğrenci sayısı, (ii) genel akademik not ortalaması (GANO) değeri, (iii) yabancı dil, (iv) bilgisayar programlama, (v) genel ofis yazılımları ve (vi) veri tabanı yönetimi yetenekleridir. Sonraki aşamada, grup-proje eşleştirmeleri gerçekleştirilmeden önce, oluşturulan grupların proje tercihleri için grup üyelerinin farklı bakış açılarını yansıtan grup kararları belirlenmektedir. Son olarak, öğrenci-proje gruplarının proje tercihlerine yönelik olarak oluşturulan grup kararları kullanılarak bir 0-1 tamsayılı program ile grup-proje atamaları gerçekleştirilmektedir. Çalışmanın literatüre olan katkısı, önerilen üç aşamalı yaklaşımla, grup kararlarının dikkate alınarak ÖPA probleminin çözülmesi şeklinde özetlenebilir. Böylelikle, farklı bakış açılarına sahip çok sayıdaki öğrencinin tercihleri, ÖPA sürecinde önemli bir kriter olan tercih kriteri için yansız ve tek bir grup kararı olarak ele alınabilmektedir. Önerilen yaklaşım, akademik bir kurumdaki gerçek bir ÖPA problemine uygulanmıştır. Elde edilen sonuçlar, ilgili literatürde bulunan diğer atama yaklaşımlarının sonuçları ile çeşitli performans parametreleri açısından karşılaştırılmıştır ve kriterlerin performans skorlarında ortalama %9 oranında iyileşme olduğu gözlemlenmiştir.</p>

EVALUATION OF DIFFERENT GROUP DECISIONS FOR THE STUDENT-PROJECT ALLOCATION PROBLEM

Keywords	Abstract
<p>Student-Project Allocation (SPA) Group Decision Mathematical Programming Integer Programming Goal Programming</p>	<p>In general, Student-Project Allocation (SPA) might be defined as a multi-criteria problem of formation of student-project groups and allocation of projects to these groups by considering different criteria. In this study, an approach including three phases is proposed for the solution of the problem. In the first phase, student-project groups are formed using a mathematical programming model adapted from a 0-1 integer-goal programming formulation in the literature. These criteria are (i) the number of students in a group, (ii) grade points average (GPA) value, (iii) language, (iv) computer programming, (v) general office software and (vi) database management skills. In the next phase, before performing group-project matchings, group decisions of the formed-groups for their project preferences are determined representing different point of views the group members. Finally, group-project allocations are performed via a 0-1 integer program using the corresponding group decisions. The contribution of the study may be summarized as solving the problem using the proposed three-phase approach by taking into account group decisions. Thus, the preferences of many students with different perspectives can be considered as an unbiased and single group decision for the preference criterion, which is an important criterion in the SPA process.</p>



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Proposed approach is implemented on a real-life SPA problem in an academic institution. The results are compared with those of the existing approaches in the related-literature with respect to some performance parameters and an average of 9% improvement is observed in the performance scores of the criteria.

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1. Giriş

Genel olarak, üniversite lisans programlarının son sınıfında öğrenim gören öğrenciler, lisans bitirme projesi dersleri kapsamında, grup halinde ilgili proje çalışmalarını gerçekleştirmektedir. Bu proje çalışmaları sayesinde, öğrencilere gerçek hayat uygulamaları üzerinde çalışma yapma, iş dünyasında yer almadan önce tecrübe kazanma ve takımlar halinde çalışma deneyimi edinme olanağı verilmektedir. İlgili projeler genellikle takım çalışması olarak gerçekleştirilmekte ve bir projeye birden fazla sayıda öğrenci atanması gerekmektedir. Bu süreç genel olarak Öğrenci-Proje Atama (ÖPA) olarak adlandırılmaktadır. ÖPA, genel bir ifadeyle çeşitli kriterlerin dikkate alınmasıyla öğrenci-proje gruplarının oluşturulmasını ve bu gruplara projelerin atanmasını içeren bir problem olarak tanımlanabilir.

İlgili literatür incelendiğinde, ÖPA probleminin farklı versiyonlarından bahsedilebilir. Bu çalışma kapsamında dikkate alınan ÖPA problemi, öğrenci-grup atamaları, grup kararlarının belirlenmesi ve grup-proje atamaları olmak üzere üç aşamadan oluşmaktadır. (Çavdur, Sebatli, Kose-Kucuk ve Rodoplu, 2019; Çavdur, Bağlarbaşı-Mutlu, Sebatli-Sağlam, 2020) tarafından yapılan çalışmalarda sunulan bir 0-1 tamsayılı-hedef programlama formülasyonundan adapte edilmiş olan matematiksel programlama modeliyle, çalışmanın ilk aşamasında çeşitli kriterler dikkate alınarak öğrenci-proje gruplarının oluşturulması gerçekleştirilmektedir. Sonraki aşamada, grup-proje eşleştirmeleri gerçekleştirilmeden önce, oluşturulan grupların proje tercihleri için grup üyelerinin farklı bakış açılarını yansıtan grup kararları belirlenmektedir. Son olarak, öğrenci-proje gruplarının proje tercihlerine yönelik olarak oluşturulan grup kararları kullanılarak bir 0-1 tamsayılı program ile grup-proje atamaları gerçekleştirilmektedir.

Çalışmanın ilk aşamasında öğrenci-grup atamaları gerçekleştirilerek öğrenci grupları oluşturulmaktadır. Oluşturulan grupların dengeli ve homojen olması, hem adil bir grup oluşmasını sağlamak hem de dolaylı olarak grup içi çeşitliliğin artmasını sağlayabilmektedir. Grupların adil olması, her grubun eşit bilgi ve beceri düzeyine sahip olmasını sağlayarak tüm grupların başarılı bir proje gerçekleştirmesini amaçlamaktadır.

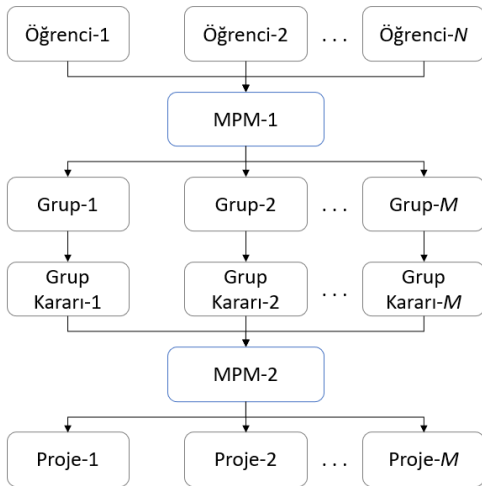
Örneğin, gruplar oluşturulurken grupların genel akademik not ortalamalarının (GANO), genel sınıf ortalamasına eşit olması adil bir sistem ortaya koymakta olup tüm grupların başarılı bir proje gerçekleştirmesini sağlayabilmektedir. Benzer şekilde, grup içi çeşitliliğin artması da gruptaki öğrencilerin motivasyonlarının artmasına ve proje çalışmalarını daha verimli bir şekilde gerçekleştirmelerine fayda sağlayabilmektedir. Öğrenci gruplarının oluşturulmasında kullanılan 0-1 tamsayılı-hedef programlama modeli Çavdur ve diğ. (2019) ve Çavdur ve diğ. (2020) tarafından gerçekleştirilen çalışmalardan adapte edilmiştir.

Öte yandan, öğrenci motivasyonlarının artmasındaki ve proje çalışmalarının daha verimli bir şekilde gerçekleştirilmesindeki en önemli unsurlardan birisi de öğrencilerin proje tercihleridir. Genel olarak, öğrencilerin daha çok ilgi duydukları projelerde çalışmaları durumunda daha verimli bir çalışma gerçekleştirmeleri beklendiğinden, ÖPA problemine dikkate alınan bileşenlerden birisi de öğrenci tercihleri olmaktadır. Bununla birlikte, pratikte çoğunlukla öğrencilerin projeler üzerinde bireysel tercihleri söz konusu olduğundan, bireysel tercihlerin grup tercihine dönüştürülmesi önemlidir. Bu çalışmanın ikinci aşamasında, oluşturulmuş olan öğrenci gruplarındaki bireysel proje tercihleri dikkate alınarak gruplar için proje tercihlerini gösteren grup kararları belirlenmektedir.

Önceki aşamalarda, sırasıyla, öğrenci gruplarının oluşturulması ve öğrencilerin bireysel proje tercihleri kullanılarak gruplar için proje tercihlerini gösteren grup kararlarının belirlenmesinden sonra, önerilen yaklaşımın son aşamasında grup-proje atamaları gerçekleştirilmektedir. Bu aşamada gerçekleştirilen grup-proje atamaları sırasında öğrencilerin bireysel tercihleri yerine grup tercihleri dikkate alınmakta ve gruplar ile projelerin birebir eşleşmesi sağlanmaktadır. Şekil 1, ÖPA için önerilen üç aşamalı yaklaşımı özetlemektedir. Şekilde de görüldüğü gibi, önerilen yaklaşımın birinci aşamasında Matematiksel Programlama Modeli-1 (MPM-1) kullanılarak öğrenci grupları oluşturulmakta, ikinci aşamada oluşturulan gruplardaki öğrencilerin bireysel proje tercihleri dikkate alınarak grubun proje tercihini gösteren grup

kararı belirlenmekte ve son aşamada da bu grup kararlarının dikkate alındığı Matematiksel Programlama Modeli-2 (MPM-2) kullanılarak grup-proje eşleştirmeleri gerçekleştirilmektedir. Konuyla ilgili mevcut çalışmalar incelendiğinde, ÖPA probleminin çözümünde genel olarak öğrencilerin bireysel tercihlerinin dikkate alındığı gözlemlendiğinden, çalışmanın literatüre olan katkısı, önerilen üç aşamalı yaklaşımla, grup kararlarının dikkate alınarak ÖPA probleminin çözülmesi şeklinde özetlenebilir. Buna ek olarak, farklı grup kararlarının değerlendirilmesi de çalışmanın bir diğer öne çıkan unsurunu oluşturmaktadır.

Çalışmanın sonraki bölümleri şu şekilde organize edilmiştir. İkinci bölümde kısa bir literatür taraması verilmiştir. Üçüncü bölüm, önerilen yaklaşımın detaylarının sunulduğu üç alt bölümden oluşmaktadır. Dördüncü bölümde elde edilen sonuçlar sunulmuştur. Son bölümde ise çalışmanın genel bir değerlendirmesi yapılmaktadır.



Şekil 1. Öğrenci-Proje Atama Aşamaları

2. Bilimsel Yazın Taraması

Literatürde yer alan ÖPA çalışmaları incelendiğinde, bu alanda bilinen ilk matematiksel programlama temelli çalışmada, Proll (1972) tarafından öğrenci tercihlerinin dikkate alındığı bir atama modeli önerilmiştir. Bir başka çalışmada, Anwar ve Bahaj (2003) ÖPA probleminin çözümü için farklı bakış açılarının yansıtıldığı iki farklı tamsayılı programlama yaklaşımı önermişlerdir. Birinci yaklaşımda; öncelikle öğrenci grupları oluşturulmakta, sonrasında her grup projelerini seçmektedir. İkinci yaklaşımda ise öğrenciler bireysel olarak projeleri seçmekte ve gruplar bu projelere atanan öğrencilerden oluşmaktadır. Pan, Chu, Han ve Huang (2009) öğrenci ve öğretim elemanı tercihlerinin yanı sıra atanan proje sayısının da optimize edilmesi amacıyla problemin çözümü için bir hedef programlama modeli

önermişlerdir. Calvo-Serrano, Guillen-Gosalbez, Kohn ve Masters (2017) önerdikleri karma-tamsayılı programlama yaklaşımıyla, sadece proje tercihlerini değil çalışma alanlarını da dikkate alarak öğrenci memnuniyetini arttırmayı amaçlamışlardır. Cavdur ve diğ. (2019) tarafından sunulan çalışmada ise tercih unsurunun yanı sıra birtakım proje kriterleri ve bu kriterleri karşılayan öğrenci nitelikleri ile kapasite kısıtları da dikkate alınarak hedef programlama temelli çözüm yaklaşımı geliştirilmiştir. Benzer bir çalışmada, Cavdur ve diğ. (2020) tamsayılı programlama ile çok-kriterli ÖPA problemini çözmüşlerdir. Ardından, problem veri setinin düzenlenebildiği, ÖPA sürecinin gerçekleştirilebildiği ve atama sonuçlarının raporlanabildiği bir karar destek sistemi uygulaması geliştirmişlerdir. Daş, Altınkaynak, Gökçen ve Türker (2022) öğrencilerin tek tek gruplara atanmasının yerine, önceden belirlenen bir dizi aday grup içerisinde proje kriterlerini sağlayan uygun grupların seçildiği hedef programlama temelli çok-amaçlı küme bölüntüleme formülasyonu önermişlerdir. Aday grupların belirlenmesinde ise bireyler arası sosyal ilişkileri ifade eden ağ yapısını dikkate almışlardır. Chiarandini, Fagerberg ve Gualandi (2019) tarafından yapılan çalışmada ise literatürdeki diğer çalışmalardan farklı olarak adalet ve kolektif memnuniyet kavramlarının üzerinde durulmuştur. ÖPA problemi karma-tamsayılı programlama formülasyonu olarak ifade edilmiş ve farklı bakış açılarını ifade eden modeller analiz edilmiştir.

ÖPA probleminde grup içi çeşitliliğin artırılması ve gruplar arası farklılıkların azaltılması grup üyelerinin motivasyonu açısından önemli olabilmektedir. Cutshall, Gavirneni ve Schultz (2007) grup üyelerinin akademik performansında eşitliğin sağlanması, grup içerisinde çeşitliliğin artırılması ve demografik açıdan dengeye ulaşılması amacıyla tamsayılı programlama temelli bir yaklaşım önermişlerdir. Borges, Dias ve Cunha (2009) ise grup içi çeşitliliğin ve gruplar arası homojenliğin maksimize edilmesi amacıyla bir algoritma önermişlerdir. Saraç ve Özçelik (2013) öğrencilerin beraber çalışmak istedikleri arkadaşlarını kendilerinin tercih ettikleri bir problem kurgusunda, öğrenci nitelikleri açısından dengeli grupların oluşturulması amacıyla bir tamsayılı programlama modeli sunmuşlardır.

Geçmiş çalışmalarda, ÖPA probleminin bir kararlı-eleştirme problemi olarak ele alındığı çalışmalar da yer almaktadır. Dye (2001) eşleştirme probleminin çözümü için kısıt programlama temelli bir çözüm yaklaşımı önermiştir. Bir başka çalışmada, Abraham, Irving ve Manlove (2007) hem öğrencilerin hem de öğretim elemanlarının tercihlerini dikkate alarak kapasite kısıtları altında sırasıyla, öğrenciler ve öğretim elemanları için en uygun sonuçları veren doğrusal-zamanlı iki algoritma sunmuşlardır. Benzer bir çalışmada, Manlove ve O'Malley (2008) problemin

kapsamını genelleştirerek bir yakınsama algoritması önermişlerdir. Iwama, Miyazaki ve Yanagisawa (2012) ise alt ve üst sınır değerlerini iyileştirilerek Manlove and O'Malley (2008) tarafından önerilen algoritmayı genişletmişlerdir. Cooper ve Manlove (2018) tercih listelerinin sıralanmasının gerekmediği ve kararlı eşleşmelerin farklı boyutlarda olabildiği senaryo için doğrusal-zamanlı yakınsama algoritması önermişlerdir. Manlove, Milne ve Olaosebikan (2018) problemin optimal çözümü için tamsayı programlama modeli önererek geçmiş çalışmalardaki yakınsama algoritmalarının performansını bu modelin performansı ile karşılaştırmışlardır. Olaosebikan ve Manlove (2020a) ise geliştirdikleri polinom-zamanlı algoritma ile süper-kararlı eşleştirmelerin bulunmasını amaçlamışlardır. Olaosebikan ve Manlove (2020b) tarafından sunulan bir diğer çalışmada, güçlü-kararlı eşleştirmelerin elde edilebilmesi için polinom-zamanlı bir algoritma önerilmiştir. Manlove, Milne ve Olaosebikan (2022) çalışmalarında, farklı karmaşıklıkta örneklerde maksimum boyutta kararlı eşleşmeleri bulmak için yaptıkları algoritmik ve deneysel çalışmaların sonuçlarını sunmuşlardır. Viet, Van Tan ve Cao (2020) tercih bazlı ÖPA problemi için maksimum zayıf-kararlı eşleşmelerin bulunması amacıyla bir algoritma önermişlerdir. Ismaili, Yamaguchi ve Yokoo (2018) ise projelere kaynak atama süreci ile öğrenci-proje eşleştirme sürecini birlikte ele almışlardır. Öğrenci-proje-kaynak atama problemi olarak adlandırılan problemde, projelere hem öğrenciler hem de kaynaklar atanmakta ve atanan kaynaklar projenin öğrenci kapasitesini belirlemektedir. Benzer bir çalışmada, Yahiro ve Yokoo (2020) öğrencilerin projeleri ve projelerin de öğrencileri tercih ettikleri öğrenci-proje-kaynak eşleştirme-atama probleminin çözümü için oyun teorisi temelli bir yaklaşım geliştirmişlerdir. Aderanti, Amosa ve Oluwatobiloba (2016) tarafından yapılan çalışmada ise ÖPA probleminin çözümü için arka planda bir eşleştirme algoritmasının kullanıldığı web-tabanlı bir sistem geliştirilmiştir.

ÖPA probleminin çözümü için literatürdeki diğer çözüm yaklaşımları incelendiğinde, birtakım sezgisel yaklaşımların varlığından söz edilebilir. Fitzpatrick, Askin ve Goldberg (2001) önerdikleri matematiksel programlama ve sezgisel tabanlı hibrit yaklaşımda, öğrencilerin teknik nitelikleriyle birlikte içgüdüsel eğilimlerini de dikkate almak için Kolbe-İndeksini kullanmışlardır. Harper, de Senna, Vieira ve Shahani (2005) öğrenciler tarafından daha fazla tercih edilen popüler projelerin hangi öğrencilere atanacaklarını belirlemek amacıyla genetik algoritma önermişlerdir. Agustin-Blas, Salcedo-Sanz, Ortiz-Garcia, Portilla-Figueras ve Perez-Bellido (2009) öğrenci laboratuvar gruplarının oluşturulması için hibrit genetik algoritma önermişlerdir. Burada, öğrenci ve öğretim elemanı tercihlerinin yanı sıra laboratuvar kapasitesi de dikkate alınmaktadır. Hübscher (2010) ise grup içi çeşitliliğin

fazla olduğu ve gruplar arasında yetenekler açısından eşitliğin bulunduğu durumda öğrenci gruplarının oluşturulması için tabu arama algoritması temelli bir yaklaşım sunmuştur. Sahin (2011) öğrenci tercihlerinin ve öğretim elemanı görüşlerinin dikkate alınarak öğrenci gruplarının oluşturulması için Prim'in minimum kapsayan ağaç algoritması temelli bir algoritma önermiş ve elde edilen sonuçları analiz etmiştir. Maashi ve diğ. (2020) tarafından yapılan çalışmada önceden belirlenen öğrenci gruplarının, aç gözlü doğrusal bir algoritma ile kapasite kısıtları ve grup tercihleri dikkate alınarak projelere atanmaları sağlanmaktadır. Binong (2021) daha iyi akademik performansa sahip öğrencileri motive etmek amacıyla, bu öğrencilerin tercihlerine daha yüksek öncelik vererek sezgisel bir algoritma ile proje atamalarını gerçekleştirmektedir. Chown, Cook ve Wilding (2018) ise öğrenci tercihlerinin yanı sıra danışman iş yükünün de dikkate alındığı bir problem kurgusu için tavlama benzetimi yaklaşımını kullanmışlardır. Kenekayoro ve Fawei (2020) sıralama temelli sezgisel yaklaşım, genetik algoritma ve karınca kolonisi optimizasyonu olmak üzere farklı yöntemler kullanarak elde edilen atama sonuçlarını analiz etmişlerdir. Alberola, Val, Sanchez-Anguis ve Julian (2016) tarafından yapılan çalışmada öncelikle içerdiği farklı grup oluşturma stratejileri ile karar vericilere test imkanı sunan, sonrasında yapay zeka yöntemleri kullanılarak grupların oluşturulmasını sağlayan genel bir çerçeve sunulmuştur.

ÖPA sürecinde bireylerin tercihlerinin dikkate alınması önceki paragraflarda da bahsedildiği gibi literatürde sıklıkla görülen bir durumdur. Öte yandan, bireylerin bir araya gelerek bir grubu oluşturması sebebiyle direkt olarak grup tercihi de ele alınabilir. Bu bakış açısı, grup karar verme tekniklerinin önemini gündeme getirmektedir. Bu bölümde, literatürde yer alan güncel grup karar verme tekniklerinden birtakım örnekler sunulmaktadır. Grup karar verme tekniklerinin birçok farklı alanda uygulandığı görülmektedir. Samanlıoğlu, Taskaya, Gulen ve Cokcan (2018) tarafından yapılan çalışmada yöneticilerin personel seçiminde hem sözel hem de sayısal ölçekteki değerlendirmelerini dikkate alabilmek için bulanık-AHP ve bulanık-TOPSIS temelli bir yaklaşım önerilmiştir. Bulanık AHP-TOPSIS hesaplamalarında, grup karar verme sürecinde, karar vericilerin sözlü değerlendirmelerinin önemini yansıtan hiyerarşik ağırlıklar kullanılmıştır. Yu, Shao, Wang ve Zhang (2019) tedarikçi seçimi için TOPSIS yaklaşımının bir uzantısı olarak aralık-değerli Pisagor bulanık ortamında grup kararının verilebildiği bir yaklaşım sunmuşlardır. Banaeian, Mobli, Fahimnia, Nielsen ve Omid (2018) ise yeşil tedarikçi seçimi problemi için bulanık-TOPSIS, bulanık-VIKOR ve bulanık-Gri İlişkisel Analiz yöntemi kullanarak elde edilen sonuçları analiz etmişlerdir. Wu, Ahmad ve Xu (2016) çok sayıda karar vericinin bulunduğu ortamda, CNC takım tezgahı seçimi için sözel bilgilerin de dikkate

alınabilmesi amacıyla bulanık-VIKOR temelli bir yaklaşım önermişlerdir. Bir başka çalışmada, Çalı ve Balaman (2019) ELECTE-I ve VIKOR yöntemlerini sezgisel bulanık bir ortamda kullanarak karar vermeyi amaçlamış, grup kararının belirlenmesinde ise entropi yöntemi ve farklı uyum kümelerinin ağırlıklarını belirlemek için ağırlıklı mesafe yaklaşımı kullanmışlardır. Kao ve Liu (2022) ise robot seçim problemi için veri zarflama metodu temelli bir grup karar verme stratejisi sunmuşlardır. Grup karar verme sürecinde çok-kriterli karar verme yöntemlerinin kullanımı ön plana çıksa da sosyal ağ analizi (Dong, Zhou ve Martinez, 2019; Zhang, Gao ve Li, 2020) kümeleme yaklaşımları (Tang, Liao, Xu, Streimikiene ve Zheng, 2020) ve optimizasyon temelli (Zhang, Dong ve Herrera-Viedma, 2019) çeşitli yaklaşımların da olduğu görülmektedir. Çavdur, Sebatlı ve Köse-Küçük (2019) çalışmalarında, ÖPA probleminde dikkate alınan kriterlerin ağırlıklarını belirlemek için AHP ve doğrusal olmayan programlama temelli hibrit bir grup karar verme yaklaşımı kullanmışlardır. Benzer bir çalışmada, AHP ile belirlenen bireysel kararların grup kararına dönüştürülmesinde aritmetik, geometrik, harmonik ve kuadratik ortalama yaklaşımları kullanılmış ve sonuçları analiz edilmiştir (Bağlarbasi-Mutlu, Sebatlı ve Cavdur, 2018). Koksalmis ve Kabak (2019) tarafından sunulan çalışmada ise grup karar vermede karar vericilerin ağırlıklarının belirlenmesi için kullanılan teknikler ile ilgili güncel literatür taraması yapılmıştır.

Bu çalışmanın öne çıkan yanı, öğrencilerin bireysel tercihlerinin yerine, birtakım kriterleri sağlamak koşuluyla oluşturulan öğrenci gruplarının tercihlerinin ele alınmasıdır. Bunun yanı sıra, gruptaki bir öğrencinin bir projede çalışmak üzere yüksek motivasyona sahip olması (projeyi ilk sıralarda tercih etmesi) veya yeterince motive olmaması (projeyi son sıralarda tercih etmesi) gibi farklı bakış açılarının probleme dahil edilmesiyle farklı grup kararları için elde edilen sonuçlar analiz edilmiştir.

3. Yöntem

Bu çalışmada araştırma ve yayın etiğine uyularak öğrencilerin projelere atanmaları için üç aşamalı bir yaklaşım kullanılmıştır. Literatürde yer alan bir 0-1 tamsayılı-hedef programlama formülasyonundan adapte edilmiş olan matematiksel programlama modeliyle, çalışmanın ilk aşamasında çeşitli kriterler dikkate alınarak öğrenci gruplarının oluşturulması gerçekleştirilmektedir (Çavdur ve diğ., 2019; Çavdur ve diğ., 2020). Sonraki aşamada, grup-proje eşleştirmeleri gerçekleştirilmeden önce, oluşturulan grupların proje tercihleri için grup üyelerinin farklı bakış açılarını yansıtan grup kararları belirlenmektedir. Son olarak, öğrenci gruplarının proje tercihlerine yönelik olarak oluşturulan grup kararları kullanılarak bir 0-1 tamsayılı program ile grup-proje atamaları

gerçekleştirilmektedir. İzleyen bölümlerde sırasıyla bu üç aşamaya ait detaylar sunulmaktadır.

3.1. Öğrenci Gruplarının Oluşturulması

Öğrencilerin gruplara atandığı ilk aşamada; (i) bir grupta yer olan toplam öğrenci sayısı, (ii) GANO, (iii) yabancı dil, (iv) bilgisayar programlama, (v) genel ofis yazılımları ve (vi) veri tabanı yönetimi bilgisi olmak üzere altı hedef dikkate alınmıştır. Bu amaçla kullanılan 0-1 tamsayılı-hedef programlama modelinde (MPM-1), ilgili altı hedeften minimum sapma ile öğrencilerin hangi gruba atanacaklarına karar verilmektedir. Bu amaçla, Cavdur ve diğ. (2019) ve Çavdur ve diğ. (2020) tarafından gerçekleştirilen çalışmalardan adapte edilen MPM-1 aşağıdaki şekilde tanımlanmaktadır.

İndisler:

i : Öğrenci indisi, $i = 1, \dots, n$

j : Grup indisi, $j = 1, \dots, m$

Parametreler:

N_S : bir grupta olması istenen kişi sayısı

$N_S^{min}(N_S^{max})$: bir grupta olması istenen kişi sayısının alt (üst) limit değeri

G_T : bir grupta olması istenen ortalama genel akademik not ortalaması değeri

$G_T^{min}(G_T^{max})$: bir grupta olması istenen genel akademik not ortalaması değerinin alt (üst) limit değeri

g_i : i . öğrencinin genel akademik not ortalaması

q_i^1 : i . öğrencinin yabancı dil yeteneğini gösteren 0-1 parametre

q_i^2 : i . öğrencinin bilgisayar programlama yeteneğini gösteren 0-1 parametre

q_i^3 : i . öğrencinin genel ofis yazılımları yeteneğini gösteren 0-1 parametre

q_i^4 : i . öğrencinin veri tabanı yönetimi yeteneğini gösteren 0-1 parametre

Değişkenler:

x_{ij} : $\begin{cases} 1, & i. \text{ öğrenci } j. \text{ gruba atanıyorsa} \\ 0, & \text{aksi durumda} \end{cases}$

$d_j^{1\pm}$: bir grupta olması istenen kişi sayısından hedefinden sapma miktarları

$d_j^{2\pm}$: bir grupta olması istenen ortalama GANO hedefinden sapma miktarları

$d_j^{3\pm}$: yabancı dil yeteneği hedefinden sapma miktarları

$d_j^{4\pm}$: bilgisayar programlama yeteneği hedefinden sapma miktarları

$d_j^{5\pm}$: genel ofis yazılımları yeteneği hedefinden sapma miktarları

$d_j^{6\pm}$: veri tabanı yönetimi yeteneği hedefinden sapma miktarları

Amaç fonksiyonu:

$$\min z = \sum_{j=1}^m (d_j^{1-} + d_j^{1+}) + \sum_{j=1}^m (d_j^{2-} + d_j^{2+}) + \sum_{j=1}^m d_j^{3-} + \sum_{j=1}^m d_j^{4-} + \sum_{j=1}^m d_j^{5-} + \sum_{j=1}^m d_j^{6-} \quad (1)$$

Kısıtlar:

$$\sum_{j=1}^m x_{ij} = 1, \quad \forall i \quad (2)$$

$$\sum_{i=1}^n x_{ij} + d_j^{1-} - d_j^{1+} = N_s, \quad \forall j \quad (3)$$

$$N_s^{\min} \leq \sum_{i=1}^n x_{ij} \leq N_s^{\max}, \quad \forall j \quad (4)$$

$$\sum_{i=1}^n g_i x_{ij} - \sum_{i=1}^n G_T x_{ij} + d_j^{2-} - d_j^{2+} = 0, \quad \forall j \quad (5)$$

$$\sum_{i=1}^n G_T^{\min} x_{ij} \leq \sum_{i=1}^n g_i x_{ij} \leq \sum_{i=1}^n G_T^{\max} x_{ij}, \quad \forall j \quad (6)$$

$$\sum_{i=1}^n q_i^1 x_{ij} + d_j^{3-} - d_j^{3+} = 1, \quad \forall j \quad (7)$$

$$\sum_{i=1}^n q_i^2 x_{ij} + d_j^{4-} - d_j^{4+} = 1, \quad \forall j \quad (8)$$

$$\sum_{i=1}^n q_i^3 x_{ij} + d_j^{5-} - d_j^{5+} = 1, \quad \forall j \quad (9)$$

$$\sum_{i=1}^n q_i^4 x_{ij} + d_j^{6-} - d_j^{6+} = 1, \quad \forall j \quad (10)$$

$$x_{ij} \in \{0,1\}, \quad \forall i, j \quad (11)$$

$$d_j^{1\pm}, \dots, d_j^{6\pm} \geq 0, \quad \forall j \quad (12)$$

Denklem (1) ile modelde dikkate alınan kriterlerin hedef değerlerinden sapmaları minimize edilmektedir. Burada dikkate alınan hedefe bağlı olarak sadece negatif veya hem pozitif hem negatif sapma değişkenlerinin minimize edilmesi söz konusudur. Denklem (2) ile her öğrencinin mutlaka bir gruba atanması sağlanmaktadır. Denklem (3) ile her grupta istenen sayıda öğrenci olması hedeflenirken, Denklem (4) ile bu sayının belirlenen alt ve üst limit değerlerinin arasında olması sağlanmaktadır. Benzer şekilde, Denklem (5) ile her grubun ortalama GANO değerinin sınıfın ortalama GANO değerine eşit olması hedeflenirken, Denklem (6) ile bu değer belirlenen alt ve üst değerlerin arasında olması sağlanmaktadır. Denklem (7)-(10) ile her grupta en az bir kişinin, sırasıyla, yabancı dil yeteneğine, bilgisayar programlama yeteneğine, genel ofis yazılımları yeteneğine ve veri tabanı yönetimi yeteneğine sahip olması hedeflenmektedir. Denklem (11) ve (12) ise genel işaret kısıtlarını ifade etmektedir.

3.2. Grup Kararlarının Belirlenmesi

Öğrencilerin gruplara atanma aşamasından sonra, oluşturulmuş olan öğrenci gruplarındaki bireysel proje tercihleri dikkate alınarak, gruplar için proje tercihlerini gösteren grup kararları belirlenmektedir. Grup kararları oluşturulurken, grup üyelerinin proje tercihlerinin ortalaması, grup üyelerinin proje tercihlerinin minimumu ve grup üyelerinin proje tercihlerinin maksimumu olmak üzere üç farklı bakış açısı dikkate alınmaktadır. Grup tercihlerinin bu üç farklı şekilde belirlenmesiyle, grupların projeleri ortalama tercih düzeylerinin yanında, her grup için grup üyeleri arasından projeleri en yüksek ve en düşük öncelikte tercih eden öğrenci tercihinin de dikkate alınması amaçlanmıştır. Öğrenci gruplarının oluşturulması, grup kararlarının belirlenmesi ve önerilen yaklaşımın daha anlaşılır olması için on öğrenci ve üç projeden oluşan örnek bir veri seti oluşturulmuştur. Burada, öğrencilerin yetenekleri rassal olarak oluşturulmuş olup GANO değerleri [1,80, 4,00] aralığında değer alan, yabancı dil yeteneğine sahip bir öğrencinin, bilgisayar programlama yeteneğine sahip üç öğrencinin, genel ofis yazılımları yeteneğine sahip sekiz öğrencinin ve veri tabanı yönetimi yeteneğine sahip iki öğrencinin bulunduğu bir veri seti oluşturulmuştur. On öğrenci için rassal olarak oluşturulan GANO (g_i), yabancı dil yeteneği (q_i^1), bilgisayar programlama yeteneği (q_i^2), genel ofis yazılımları yeteneği (q_i^3) ve veri tabanı yönetimi yeteneği (q_i^4) değerleri Tablo 1'de gösterilmiştir.

Tablo 1. Örnek Veri Seti için Öğrenci Parametreleri

Öğrenci	g_i	q_i^1	q_i^2	q_i^3	q_i^4
1	3,10	0	0	1	1
2	1,89	0	0	1	0
3	4,00	1	1	1	0
4	1,80	0	1	1	0
5	3,50	0	0	1	0
6	3,40	0	0	1	0
7	2,31	0	0	0	0
8	3,30	0	0	1	0
9	3,21	0	0	1	1
10	2,65	0	1	0	0

Öğrenci gruplarının oluşturulması için MPM-1'in çözümünde kullanılan parametreler; N_s^{\min} (N_s^{\max}) değerleri 2 (4), N_s değeri 3, G_T^{\min} (G_T^{\max}) değerleri 2,60 (3,20) ve G_T değeri 2,90 olarak belirlenmiştir. Bu değerler ilgili rassal veri setinin özellikleri (örneğin, öğrenci yeteneklerinin ortalamaları) dikkate alınarak hesaplanmıştır. Oluşturulan öğrenci gruplarının, grup kararlarının nasıl belirlendiği Tablo 2'de gösterilmiştir.

Tablo 2'nin sol kısmında öğrencilerin atandıkları proje grupları ve bireysel proje tercihleri görülmektedir. Tablo 2'de sağa doğru gruplandırılmış şekilde

gösterilen üç matris ise sırasıyla her grup için hesaplanan ortalama, minimum ve maksimum tercih düzeylerini göstermektedir.

Tablo 2. Örnek Veri Seti için Grup Kararları

Ö	G	Bireysel Tercihler				Ortalama Tercih				Minimum Tercih				Maksimum Tercih			
		ÖT	P1	P2	P3	GT	P1	P2	P3	GT	P1	P2	P3	GT	P1	P2	P3
Ö1	G1	Ö1	2	3	1	G1	2,00	2,00	2,00	G1	1	1	1	G1	3	3	3
Ö2		Ö2	1	2	3	G2	2,33	2,00	1,67	G2	1	1	1	G2	3	3	2
Ö3		Ö3	3	1	2	G3	1,75	2,50	1,75	G3	1	2	1	G3	3	3	3
Ö4	G2	Ö4	3	1	2												
Ö5		Ö5	1	3	2												
Ö6		Ö6	3	2	1												
Ö7	G3	Ö7	1	2	3												
Ö8		Ö8	1	3	2												
Ö9		Ö9	2	3	1												
Ö10		Ö10	3	2	1												

Ö: Öğrenci, G: Grup, P: Proje, ÖT: Öğrenci Tercihi, GT: Grup Tercihi

Tablo 2 incelendiğinde örneğin, üç öğrenciden oluşan ilk grubun, birinci projeyi ortalama tercih düzeyi $avg\{2,3,1\} = 2$, minimum tercih düzeyi $min\{2,3,1\} = 1$ ve maksimum tercih düzeyi de $max\{2,3,1\} = 3$ olarak belirlenmiştir. Diğer bir ifadeyle, grupta projeyi ilk sırada tercih eden bir öğrenci, ikinci sırada tercih eden bir öğrenci ve üçüncü sırada tercih eden bir öğrenci bulunmakta olup, grupta üç kişi yer aldığından projenin ortalama tercih düzeyi iki olarak belirlenmiştir. Diğer girdiler de benzer şekilde yorumlanabilir. Tablo 2'de açıklanan tercih düzeyi belirleme şeklinin formal bir şekilde ifade edilmesi amacıyla, i öğrenci indisi, j grup indisi, k proje indisi, x_{ij} birinci aşamada elde edilen çözümden gelen (i . öğrenci j . gruba atanıyorsa 1, aksi durumda 0 değerini alan) değişkenler ve p_{ik} i . öğrencinin k . projeyi tercih düzeyi olmak üzere, j grubunun k projesi için ortalama proje tercih düzeyi, Denklem (13) ile hesaplanmaktadır.

$$gp_{jk}^{(avg)} = avg\{p_{ik}x_{ij}\}, \quad \forall j, k \quad (13)$$

Benzer şekilde, her grup için grup üyeleri arasından projeleri en yüksek ve en düşük öncelikte tercih eden öğrenci tercihinin de dikkate alınması amacıyla hesaplanan grup üyelerinin tercihlerinin minimumu ve maksimumu da Denklem (14) ve Denklem (15) ile belirlenmektedir.

$$gp_{jk}^{(min)} = min\{p_{ik}x_{ij}\}, \quad \forall j, k \quad (14)$$

$$gp_{jk}^{(max)} = max\{p_{ik}x_{ij}\}, \quad \forall j, k \quad (15)$$

3.3. Grup Proje Atamalarının Gerçekleştirilmesi

Grup tercihlerinin belirlenmesinin ardından, önerilen yaklaşımın son aşamasında grup-proje eşleştirmeleri

gerçekleştirilmektedir. Bu amaçla, önceki aşamada belirlenmiş olan grup tercihlerinin atama maliyeti olarak ele alındığı genel atama modeli için 0-1 tamsayılı programlama modeli kullanılarak, gruplar için oluşturulan ortalama, minimum ve maksimum tercih düzeyleri dikkate alınarak grup-proje eşleştirmeleri gerçekleştirilmiştir. Bu aşamada kullanılan model aşağıdaki şekilde tanımlanmaktadır.

İndisler:

j : Grup indisi, $j = 1, \dots, m$

k : Proje indisi, $k = 1, \dots, m$

Parametreler:

gp_{jk} : j . grubun k . projeyi tercih etme düzeyi

Değişkenler:

x_{jk} : $\begin{cases} 1, & j. \text{ grup } k. \text{ projeye atanıyorsa} \\ 0, & \text{aksi durumda} \end{cases}$

Amaç fonksiyonu:

$$\min z = \sum_{j=1}^m \sum_{k=1}^m gp_{jk}x_{jk} \quad (16)$$

Kısıtlar:

$$\sum_{k=1}^m x_{jk} = 1, \quad \forall j \quad (17)$$

$$\sum_{j=1}^m x_{jk} = 1, \quad \forall k \quad (18)$$

$$x_{jk} \in \{0,1\}, \quad \forall j, k \quad (19)$$

Denklem (16) ile grup kararları dikkate alınarak belirlenen tercih düzeyleri minimize edilerek, grupların en yüksek düzeyde tercih ettikleri projeler atanması amaçlanmaktadır. Denklem (17) ile her grup bir projeye ve Denklem (18) ile her proje bir gruba

atanmaktadır. Denklem (19) genel işaret kısıtını ifade etmektedir.

4. Bulgular

Bu çalışmada ÖPA problemi için önerilen çözüm yaklaşımı gerçek bir problem üzerinde uygulanmış ve elde edilen sonuçların performansı analiz edilmiştir. Çalışma kapsamında ÖPA problemi için üç yıla ait veri seti kullanılmıştır (Cavdur, 2018). Kullanılan veri setlerine ait öğrenci ve proje sayısı Tablo 3'te gösterilmiştir.

Tablo 3. Problem Veri Setlerinin Özellikleri

	Veri Seti-1	Veri Seti-2	Veri Seti-3
Öğrenci Sayısı	70	68	73
Proje Sayısı	25	22	24

Çalışmanın ilk aşamasında öğrenci gruplarının oluşturulması sırasında kullanılan MPM-1 modeli ile (i) bir grupta yer alan toplam öğrenci sayısı, (ii) GANO, (iii) yabancı dil, (iv) bilgisayar programlama, (v) genel ofis yazılımları ve (vi) veri tabanı yönetimi bilgisi olmak üzere altı kriter ele alınırken, çalışmanın son aşamasında grup-proje eşleştirmelerinin gerçekleştirilmesi sırasında kullanılan MPM-2 modeli ile de grupların proje tercihleri dikkate alınmaktadır. Dolayısıyla, bütünlük olarak değerlendirildiğinde ilgili matematiksel programlama modelleri ile toplamda yedi kriter dikkate alınarak ÖPA problemi çözülmekte ve önerilen yaklaşımın performansı söz konusu yedi kritere ait normalize edilmiş yüzdeler kullanılarak incelenmektedir. Herhangi bir kritere ait yüzdeler performans skoru (%100 olabilecek en iyi performans skorunu göstermek üzere) ilgili kriterin sağlanma düzeyini göstermektedir. Söz konusu modellerin çözümü Intel(R) Core(TM) i5-10210U CPU @ 1.60GHz 2.11 GHz özelliklerinde bir bilgisayar ortamında GAMS ara yüzü kullanılarak CPLEX çözücüsü ile gerçekleştirilmiştir.

Bu çalışmada, önerilen yaklaşıma ek olarak, literatürden adapte edilen iki farklı yaklaşım da uygulanmış ve performansları önerilen yaklaşımın performansı ile kıyaslanmıştır. Literatürden adapte edilen yaklaşımlardan ilki, Cavdur ve diğ. (2019) tarafından önerilen tüm kriterlerin (toplam yedi kriterin) dikkate alındığı ve ilgili çalışmadan adapte edilen formülasyonla problemin çözüldüğü durumu, diğeri ise yine Cavdur ve diğ. (2019) tarafından önerilen tüm kriterlerden tercih dışındaki kriterlerin (toplam altı kriter) dikkate alındığı ve ilgili çalışmadan adapte edilen formülasyonla problemin çözüldüğü durumu ifade etmektedir. Böylece, yine tercih dışındaki tüm kriterlerin dikkate alınmış olduğu bu çalışmada Önerilen Yaklaşım (ÖY) ile de uyumlu olacak şekilde bir kurgu oluşturulmuş olmaktadır. Literatürden adapte edilen iki yaklaşımdan birincisinde tüm kriterlerin

dikkate alınması, diğerinde ise tercih dışındaki tüm kriterlerin dikkate alınması nedeniyle, ilgili yaklaşımlar da tercih kriterinin sırasıyla dikkate alındığını ve alınmadığını ifade etmek amacıyla YT+ ve YT- şeklinde gösterilmiştir. Sonuç olarak, bu bölümde (i) tercihle birlikte tüm kriterlerin dikkate alındığı yaklaşım (YT+), tercih dışındaki tüm kriterlerin dikkate alındığı yaklaşım (YT-) ve önerilen yaklaşım (ÖY) olmak üzere üç farklı yaklaşıma ait performans skorları kıyaslanmıştır. Önceki bölümde de belirtildiği gibi önerilen yaklaşım kapsamında tercih kriteri açısından farklı bakış açılarını yansıtmak amacıyla üç farklı grup kararı değerlendirilmiş ve bunlara karşılık gelen performans skorları, önceki bölümde ele alındıkları şekilde, grubun ortalama, iyimser ve kötümser bakış açılarını ifade ettikleri varsayılmıştır. Bir diğeri ifadeyle, ilgili grup kararları, grubun tercih düzeyi ortalamasını (ÖY-O), projeyi en üst sırada tercih eden öğrencinin tercih düzeyini (ÖY-İ) ve projeyi en alt sırada tercih eden öğrencinin tercih düzeyini (ÖY-K) dikkate aldığından, tercih kriterinin ilgili performans skorları sırasıyla; ortalama, iyimser ve kötümser bakış açılarına karşılık gelen skorlar olarak ifade edilmekte ve sonuç tablolarında tercih kriteri kısmında ilgili bakış açılarına karşılık gelen üç farklı değer şeklinde ifade edilmektedir. Diğer yaklaşımlardan elde edilen ve ayrıca söz konusu bakış açılarını da yansıtan grup kararları dikkate alınarak hesaplanan performans skorları çalışma kapsamında kullanılan üç farklı veri seti için Tablo 4'te verilmiştir. Tabloda her bir veri seti için optimal çözümlerin elde edildiği çözüm süreleri de saniye cinsinden verilmiş olup bu değerler minimum 41,89, ortalama 51,01 ve maksimum 71,02 saniyedir. Tabloda yer alan performans skorlarının nasıl hesaplandığı aşağıdaki gibi özetlenebilir:

(i) Tercih kriteri için hesaplanan performans skoru Denklem (20) ile verilen ifadede olduğu gibi tercih hedefinden sapmaların ağırlıklandırılmasına dayanarak belirlenmektedir. Bir diğeri ifadeyle, ideal durumda her öğrencinin birinci tercihi atanacağı düşünülürse $(p_{ij} - 1)$ ile bu durumdan sapmalar hesaplanmaktadır. Ardından, sapma değerlerinin ağırlıklı ortalamasının birden çıkartılması ile Tercih Performans Skoru (TPS) hesaplanmaktadır. Buradaki p^{max} değeri ise tercih kriteri üst sınırıdır.

$$TPS = 1 - \frac{\sum_{i=1}^n \sum_{j=1}^m (p_{ij} - 1) x_{ij}}{p^{max} n} \quad (20)$$

(ii) Gruptaki öğrenci sayısı kriterinin performans skoru hesaplanırken öncelikle her gruba atanan öğrenci sayısı belirlenmektedir. Ardından bir grupta olması istenen kişi sayısına (N_s) eşit sayıda öğrenciye sahip grup sayısı, toplam grup sayısına (m) bölünmektedir.

Tablo 4. ÖPA Problemi Sonuçları

	Performans Ölçütü	YT+	YT-	ÖY-O/i/K	İyileşme Oranı
Veri Seti-1	Tercih	0,85	0,29	0,62 / 0,95 / 0,36	%-27 / %12 / %-58 : %-24
	Gruptaki Öğrenci Sayısı	0,56	0,80	0,80	%43
	GANO	0,97	0,99	0,99	%2
	Yabancı Dil	1,00	1,00	1,00	%0
	Bilgisayar Programlama	0,88	1,00	1,00	%14
	Genel Ofis Yazılımları	0,88	1,00	1,00	%14
	Veri Tabanı Yönetimi	0,52	0,52	0,52	%0
	Diğer Kriterlerin Ort. Performans Skoru	0,79	0,89	0,89	Ortalama İyileşme Oranı
	Çözüm Süresi (saniye)	41,89	48,20	44,92 / 44,78 / 44,73	%7
Veri Seti-2	Tercih	0,94	0,46	0,57 / 0,98 / 0,48	%-39 / %4 / %-49 : %-28
	Gruptaki Öğrenci Sayısı	0,45	0,91	0,91	%102
	GANO	0,96	0,99	0,99	%3
	Yabancı Dil	0,45	0,55	0,55	%22
	Bilgisayar Programlama	1,00	1,00	1,00	%0
	Genel Ofis Yazılımları	1,00	1,00	1,00	%0
	Veri Tabanı Yönetimi	0,95	1,00	1,00	%5
	Diğer Kriterlerin Ort. Performans Skoru	0,80	0,91	0,91	Ortalama İyileşme Oranı
	Çözüm Süresi (saniye)	41,97	42,30	44,61 / 44,70 / 44,57	%15
Veri Seti-3	Tercih	0,87	0,15	0,42 / 0,94 / 0,15	%-52 / %8 / %-83 : %-42
	Gruptaki Öğrenci Sayısı	0,63	0,96	0,96	%52
	GANO	0,97	0,99	0,99	%2
	Yabancı Dil	0,38	0,46	0,46	%21
	Bilgisayar Programlama	1,00	1,00	1,00	%0
	Genel Ofis Yazılımları	1,00	1,00	1,00	%0
	Veri Tabanı Yönetimi	0,75	0,79	0,79	%5
	Diğer Kriterlerin Ort. Performans Skoru	0,79	0,87	0,87	Ortalama İyileşme Oranı
	Çözüm Süresi (saniye)	43,61	70,17	68,81 / 68,83 / 71,02	% 6

(iii) GANO kriterine ait performans skoru hesaplanırken öncelikle her grubun ortalama GANO değerinin bir grupta olması istenen ortalama GANO (G_T) değerinden mutlak değerce sapmaları yüzdesel olarak belirlenmektedir. Ardından, bu sapma değerlerinin ortalamasının birden çıkartılması ile GANO kriterinin tatmin düzeyi hesaplanmaktadır.

(iv) Yabancı dil kriterine ait sapma değeri hesaplanırken her bir gruba atanan öğrenciler arasında en az bir kişinin yabancı dil yeteneğine sahip olup olmadığı kontrol edilmektedir. Ardından, en az bir kişinin ilgili kriteri sağladığı grup sayısı, toplam grup sayısına (m) bölünerek performans skoru hesaplanmaktadır. Diğer kriterler (bilgisayar programlama, genel ofis yazılımları ve veri tabanı yönetimi yetenekleri) için de benzer yaklaşımla performans skoru hesaplanmaktadır.

Özetle, tüm performans skorlarının ilgili kriterlere ait hedef değerlerin tatmin edilmesine ilişkin oranı ifade ettiği ve $[0,1]$ arasında değer aldığı söylenebilir. Burada bire yakın değerler ilgili kriterin yüksek oranda karşılandığı anlamına gelmektedir.

Tablolardaki performans skorlarının detaylı olarak incelenmesinden önce, önerilen yaklaşımın üç aşamasında (i) tercih kriteri dikkate alınmadan öğrenci gruplarının oluşturulduğu, (ii) oluşturulan gruplardaki bireysel öğrenci tercihleri kullanılarak grup kararlarının belirlendiği ve (iii) grupların proje tercihlerine ait grup kararları dikkate alınarak grup-proje eşleştirmelerinin gerçekleştirildiğinin tekrarlanması faydalı olacağı düşünülmektedir. Bir diğer ifadeyle, önerilen yaklaşımda grupların oluşturulması sırasında tercih kriteri dikkate alınmamaktadır. Bu açıdan bakıldığında, beklendiği şekilde, ÖY-O sütununda verilen tercih skoruna ait

performans değerlerinin, tercih kriterinin hiç dikkate alınmadığı YT- ve tercih kriterinin de dikkate alınarak grupların oluşturulduğu YT+ arasında yer aldığı görülmektedir. Benzer şekilde, önerilen yaklaşımda tercih kriteri için iyimser bakış açısının değerlendirilmesi durumunda ise yine beklendiği şekilde, iyimser bakış açısına karşılık gelen ÖY-İ sütunundaki tercih kriterine ait performans skorlarının veri seti için en yüksek performans skorlarına karşılık geldiği görülmektedir. Önerilen yaklaşımda, tercih kriteri için kötümser bakış açısının değerlendirilmesi durumunda ise kötümser bakış açısına karşılık gelen ÖY-K sütununda verilen tercih skoruna ait performans değerlerinin beklendiği şekilde, tercih kriterinin hiç dikkate alınmadığı YT- performans skoruna eşit veya YT- performans skoru ve tercih kriterinin de dikkate alınarak grupların oluşturulduğu YT+ performans skoru arasında olduğu görülmektedir. Öte yandan, önerilen yaklaşım ile tercih dışındaki tüm kriterler dikkate alınarak gruplar oluşturulduğundan, yine beklendiği şekilde, diğer kriterler açısından önerilen yaklaşımın performans skorlarının genel olarak YT- yaklaşımıyla paralel olacak şekilde ve YT+ yaklaşımından daha yüksek skorlar üretmesi beklenecektir.

Örneğin Veri Seti-3 için performans skorları incelendiğinde, tercih kriterine açısından ÖY-O sütununda yer alan %42 değerinin, YT- sütununda yer alan %15 ve YT+ sütununda yer alan %87 değerleri arasında yer aldığı ve benzer şekilde, ÖY-İ ve ÖY-K sütunlarında yer alan değerlerin de sırasıyla en yüksek ve en düşük performans skorları olan %94 ve %15 değerlerine karşılık geldiği görülmektedir. Diğer kriterler açısından incelendiğinde ise yine ÖY sütununda yer alan değerlerin YT- sütunundaki değerlerle eşit ve YT+ sütunundaki değerlerden daha yüksek oldukları görülmektedir. Örneğin Veri Seti-3 için diğer kriterlerin ortalama performansı skorunun, ÖY ve YT- için %87 iken, YT+ için ise bu değer 79% olduğu görülmektedir. Veri Seti-3 için gerçekleştirilen bu gözlemlerin genel olarak diğer veri setleri için de geçerli olduğu görülmektedir.

Tablo 4'ün son sütununda ise önerilen yaklaşım ile elde edilen sonuçların (ÖY performansının) literatürde yer alan yaklaşım ile elde edilen sonuçlara (YT+ performansına) kıyasla performans ölçütlerinde meydana getirdiği iyileştirme oranları sunulmuştur. Örneğin, Veri Seti-1 için gruptaki öğrenci sayısı kriterinin performansı 0,56 değerinden 0,80 değerine çıkarak %43 iyileştirme elde edilmiştir. Diğer iyileştirme oranları da benzer şekilde hesaplanmıştır. Tercih kriteri için ortalama, iyimser ve kötümser bakış açılarının ait oranlar ayrı ayrı hesaplanırken ilgili alanda yazan son değer olarak bu üç değer ortalama da sunulmuştur. Her bir veri seti için tüm kriterlerin ortalama iyileştirme oranları hesaplanmış olup bu değerler sırasıyla %7, %15, %6'dır.

5. Tartışma ve Sonuçlar

ÖPA, genel olarak, çeşitli kriterlerin dikkate alınmasıyla öğrenci-proje gruplarının oluşturulmasını ve bu gruplara projelerin atanmasını içeren bir problem olarak tanımlanabilir. Bu çalışmada, problemin çözümü için üç aşamadan oluşan bir yaklaşım önerilmektedir. Literatürde yer alan bir 0-1 tamsayılı-hedef programlama formülasyonundan adapte edilmiş olan matematiksel programlama modeliyle, çalışmanın ilk aşamasında çeşitli kriterler dikkate alınarak öğrenci-proje gruplarının oluşturulması gerçekleştirilmektedir. Sonraki aşamada, grup-proje eşleştirmeleri gerçekleştirilmeden önce, oluşturulan grupların proje tercihleri için grup üyelerinin farklı bakış açılarını yansıtan grup kararları belirlenmektedir. Son olarak, öğrenci-proje gruplarının proje tercihlerine yönelik olarak oluşturulan grup kararları kullanılarak bir 0-1 tamsayılı program ile grup-proje atamaları gerçekleştirilmektedir. Çalışmanın literatüre olan katkısı, önerilen üç aşamalı yaklaşımla, grup kararlarının dikkate alınarak ÖPA probleminin çözülmesi şeklinde özetlenebilir. Önerilen yaklaşım, akademik bir kurumdaki gerçek bir ÖPA problemine uygulanmıştır. Elde edilen sonuçlar, ilgili literatürde bulunan diğer atama yaklaşımlarının sonuçları ile çeşitli performans parametreleri açısından karşılaştırılmıştır.

Yukarıdaki paragrafta da belirtildiği gibi, çalışmanın literatüre olan katkısı, önerilen üç aşamalı yaklaşımla, grup kararlarının dikkate alınarak ÖPA probleminin çözülmesi şeklinde ifade edilebilir. Literatürdeki çalışmalar incelendiğinde, tercih kriterinin genel olarak bireysel öğrenci tercihleri şeklinde ve çoğunlukla grupların oluşturulması sırasında dikkate alındığı görülmektedir. Bir diğer ifadeyle, ÖPA probleminde grupların oluşturulması ve projelere atanması işlemleri birlikte gerçekleştirilirken, öğrencilerin bireysel olarak proje tercihleri de dikkate alınmakta, sonuçta ortaya çıkan öğrenci gruplarının atandıkları projeler için grup kararları bir anlamda dolaylı olarak bu şekilde dikkate alınmış olmaktadır. Bu şekilde uygulanan bir yaklaşımın da doğal olarak ÖPA problemi için geçerli olduğu ve tercih kriterini de dikkate alması nedeniyle başarılı sonuçlar elde edildiği görülmektedir. Bu çalışma kapsamında ise tercih kriteri dikkate alınmadan grupların oluşturulması ve oluşturulan grupların proje tercihleri için grup üyelerinin farklı bakış açılarını yansıtan grup kararları dikkate alınarak grup-proje eşleştirmelerinin gerçekleştirilmesi yaklaşımının değerlendirilmesi amaçlanmıştır. Böyle bir yaklaşımın özellikle grup üyelerinin sıra dışı tercihlerin dikkate alınması açısından anlamlı olabileceği düşünülmektedir. Bu amaçla, grup kararı olarak grupların ortalama tercihlerinin dikkate alınmasına ek olarak, gruptaki en yüksek ve en düşük düzeydeki tercihleri dikkate alan iyimser ve kötümser bakış açıları da çalışma kapsamında ele alınmıştır.

Önerilen yaklaşım, beklendiği şekilde, tercih kriterinde ortalamada bir kötüleşmeye yol açarken, tercih dışındaki diğer kriterler açısından daha iyi sonuçlar üretmektedir. Bununla birlikte, tercih kriterini bireysel öğrenci tercihlerinin ortalaması şeklinde dikkate almak yerine, bu çalışmada önerildiği şekilde, iyimser, kötümser veya buna benzer diğer bakış açılarıyla ele alınması durumunda, farklı değerlendirmeler yapılabileceği görülmektedir.

Gelecek çalışmalarda, önerilen yaklaşım çeşitli açılardan geliştirilebilir. Bunlar arasında, özellikle grup kararı unsurunun öne çıkabileceği kurgulardan birisi de öğrencilerin sadece proje tercihlerinin dikkate alınmasına ek olarak, grup üyeleri olarak birbirilerine olan tercihleri göz önünde bulundurularak grupların oluşturulması şeklinde olabilir. Bu çalışma kapsamında ÖPA probleminde danışman atamaları, danışmanlar için benzer bir grup oluşturma verileri halihazırda mevcut olmadığından dikkate alınmamıştır. Bununla birlikte, gelecek çalışmalar kapsamında, danışman atamaları da problem kapsamına dahil edilebilir. Çalışma kapsamında dikkate alınan ve çalışmanın öne çıkan unsuru olan bireysel tercihlerin dikkate alınarak grup kararının oluşturulması fikri bu çalışmada örnek bazı bakış açıları kullanılarak değerlendirilmiş olup, gelecek çalışmalarda grup kararı oluşturma ve buna yönelik atamalar yapma süreci daha da kapsamlı hale getirilebilir. Çalışma kapsamında birinci ve üçüncü aşamalarda sırasıyla grup oluşturma ve grup-proje eşleştirmeleri için kullanılan matematiksel programlama modelleri daha farklı açılardan geliştirilebileceği gibi özellikle büyük boyutlu problemler için alternatif çözüm yaklaşımları da dikkate alınabilir.

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Çıkar Çatışması

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TOZALTI ARK KAYNAK (SAW) YÖNTEMİNDE KAYNAK GENİŞLİĞİNİN TAGUCHİ METODUYLA OPTİMİZASYONU

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Anahtar Kelimeler	Öz
Taguchi Metodu, Tozaltı Ark Kaynağı, Helezonlar, Tozaltı Kaynak Makinesi Tasarımı	<p><i>Dikey karıştırıcı öğütücüler, çeşitli maden cevherinin ekonomik olarak öğütülmesinde kullanılırlar. Karıştırma vidası öğütme haznesinin üstüne dik eksenli çalışacak şekilde yataklanması yapılır. Öğütücü karıştırma sırasında oluşan zorlanmalara karşı mukavim olması ve rijitliğini koruması istenir. Bu nedenle parçalar birleştirilirken Tozaltı Ark Kaynağı (SAW) yöntemi seçilmiştir.</i></p> <p><i>Bu çalışmada, Genichi Taguchi tarafından kurulan yöntem kullanılmıştır. Genel olarak tasarım değişkenlerini optimize etmek için benimsenmiştir. Çünkü bu yöntem genel test süresini ve maliyetleri önemli ölçüde azaltmaktadır. Özel olarak tasarlanan VTM Tozaltı Ark Kaynak Tezgâhında, Hardox 400 (400HBW) nominal sertliğe sahip aşınmaya dayanıklı çelik malzemenin kaynak işlemleri yapılmıştır. Tasarlanan bu tezgâhta vidaların kaynak edilmesi aynı anda çift taraflı otomatik olarak birleştirme işlemleri gerçekleştirilmiştir. Daha sonra kaynak genişlikleri ölçülmüştür. SAW makinesi ile kaynak yapılmış deney numuneleri Taguchi'nin deney tasarımına göre veriler toplanmış ve sürecin girdi-çıkış ilişkilerini kurmak için varyans (ANOVA: Analysis of Variance) ve regresyon analizi yapılmıştır. Elde edilen bu verilerin ışığında tozaltı ark kaynak işleminin Taguchi yöntemi ile en iyilenmesi uygulaması için Minitab programında analizleri elde edilmiştir. Bu analizlerden elde edilen optimize edilmiş değerler deneysel sonuçlarla karşılaştırılmıştır. Yapılan analizler sonucu elde edilen verilere göre eniyilenmesi değerleri A2B2C2D1'de elde edilmiştir. Değerler; Kaynak akımı (37,17), Kaynak hızı (37,20), elektrot çıkıntısı (37,41) ve Isı girişi (37,23) olarak tespit edilmiştir. Sinyal-gürültü oranı (S/N) grafiğinde en çok etkileyen faktörlerin elektrot çıkıntısı ve ısı girişi en az etkileyen ise kaynak akımı ve kaynak hızı olduğu görülmüştür.</i></p>

THE OPTIMIZATION OF WELDING WIDTH BY TAGUCHI TECHNIQUE IN SUBMERGED ARC WELDING (SAW) METHOD

Keywords	Abstract
Taguchi Method, Submerged Arc Welding, Spirals, Submerged Arc Welding Machine Design	<p><i>The vertical mixer grinders used in this study are used for economical grinding of various mineral ores. The mixing screw is placed on the top of the grinding chamber in such a way that it works vertically. It is required that the grinder should be resistant to the strains that occur during mixing and maintain its rigidity. For this reason, submerged arc welding (SAW) method was chosen when joining the parts.</i></p> <p><i>In this study, the method established by Genichi Taguchi was used because this method significantly reduces overall testing time and costs, it is generally adopted to optimize design variables.</i></p> <p><i>In the specially designed VTM Submerged Arc Welding Machine, welding processes of wear-resistant steel material with a nominal hardness of Hardox 400 (400HBW) were performed. In this designed workbench, the welding of the screws and the double-sided automatic joining processes were carried out at the same time.</i></p> <p><i>Then weld widths were measured. Test samples welded with SAW machine, and data were collected according to Taguchi's experimental design and variance (ANOVA: Analysis of Variance) and regression analysis were performed to establish the input-output relations of the process. In the light of these data obtained, analyzes were made</i></p>

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in the Minitab program for the application of the submerged arc welding process to be optimized with the Taguchi method. The optimized values obtained from these analyzes were compared with the experimental results. According to the data obtained from the results of the analyzes, optimal values were obtained in A2B2C2D1.Values; Welding current (37.17), Welding speed (37.20), electrode protrusion (37.41) and Heat input (37.23) were established. In the signal-to-noise ratio (S/N) graph, the most influencing factors were the electrode protrusion and the heat input, the least affecting being the welding current and welding speed.

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1. Giriş

Kalite, günümüz küresel ve ekonomik liberalleşmede rekabet avantajı elde etmek için önemli faktörlerden biri haline gelmiştir. Kaliteli bir ürün veya hizmet, bir kuruluşun müşteri artışını ve devamlılığını sağlar. Düşük kalite, memnuniyetsiz müşterilere yol açar, bu nedenle düşük kalitenin maliyetleri yalnızca anlık israf veya düzeltme maliyetleri değil, aynı zamanda gelecekteki satışların da kaybıdır (Deshmukh, ve Sorte, 2013). Tozaltı Ark Kaynağı (SAW), derin penetrasyon ve pürüzsüz bir dikiş gibi avantajları nedeniyle endüstrideki en önemli kaynak yöntemlerinden biridir. Gerekli kaynak parçası kalitesini elde etmek için kontrol edilmesi gereken tozaltı ark kaynak işleminde birçok kritik girdi parametresi yer almaktadır.

Çevrimdışı kalite kontrol yöntemleri, ürün üretilebilirliğini ve güvenilirliğini artırmak, ürün geliştirme ve ömür boyu maliyetlerini azaltmak için ürün ve süreç tasarım aşamalarında gerçekleştirilen kalite ve maliyet kontrol faaliyetleridir. Parametre tasarımı, çevrim dışı bir kalite kontrol yöntemidir. Ürün tasarımı aşamasında, parametre tasarımının amacı, ürünün performansını çevresel değişkenlerin, bozulmanın ve üretim değişikliklerinin etkilerine karşı daha az duyarlı hale getiren ürün tasarım özelliklerinin ayarlarını belirlemektir. Parametre tasarımı, değişkenlik kaynaklarının etkisini kontrol etmek yerine azaltarak performans değişimini azalttığından, ürün kalitesini iyileştirmek için çok uygun bir tekniktir (İç ve Yıldırım, 2012).

2. Bilimsel Yazın Taraması

2.1. Taguchi Yöntemi

Taguchi'nin teknikleri mühendislik tasarımında yaygın olarak kullanılmaktadır (Ross, 1996; Phadke, 1989). Taguchi tekniklerinin temel güveni, minimum

varyasyon ile bir kalite karakteristiğinin (performans ölçüsü) en iyi seviyelerini üreten parametre (faktör) ayarlarını belirlemeye yöneliktir. Taguchi tasarımları, çeşitli koşullarda tutarlı ve optimum şekilde çalışan süreçlerin tasarlanması için güçlü ve verimli bir yöntem sağlar. En iyi tasarımı belirlemek için, süreci çeşitli tasarım parametreleri seviyelerine maruz bırakan stratejik olarak tasarlanmış bir deneyin kullanılmasını gerektirir. Deneysel tasarım yöntemleri 20. yüzyılın başlarında geliştirilmiş ve o zamandan beri istatistikçiler tarafından kapsamlı bir şekilde araştırılmıştır. Ancak uygulayıcılar tarafından kullanımı pek kolay olmamıştır. Taguchi'nin deney tasarımı yaklaşımının benimsenmesi ve istatistik konusunda sınırlı bilgisi olan kullanıcılar için uygulanması kolay; bu nedenle mühendislik ve bilim alanında geniş bir popülerlik kazanmıştır. Proses optimizasyonu için malzeme işlemede Taguchi tekniklerinin birçok yeni uygulaması olmuştur (Yang ve Trang, 1998; Su, Yao, Wei, Kao ve Wu, 2013; Nian, Yang ve Tarng, 1999; Lin, 2002; Davim, 2003).

Japon kalite yönetim danışmanı Dr. Genichi Taguchi, proses kontrol parametrelerinin optimum ayarıyla deney için çok daha az varyans sağlayan ortogonal dizi deneylerine dayalı bir yöntem geliştirmiştir. Ortogonal dizi, bir dizi minimum deney çalıştırması sağlar ve istenen çıktının logaritmik işlevleri olan Taguchi'nin sinyal-gürültü oranları, optimizasyonun nesnel işlevleri olarak hizmet eder. Bu teknik, veri analizinde ve optimum sonuçların tahmininde yardımcı olmaktadır. Optimum parametre ayarlarını değerlendirmek için Taguchi yöntemi, sinyal-gürültü oranı adı verilen istatistiksel bir performans ölçüsü kullanır. Sinyal-gürültü oranı, ortalamanın (sinyal) standart sapmaya (gürültü) oranıdır. Genel olarak kullanılan standart S/N oranı şu şekildedir; Nominal-en-En İyidir (NB), Daha Düşüktür (LB) ve Daha Yüksek (HB). Optimum ayar, en yüksek S/N oranına sahip olan parametre kombinasyonudur (Kumar ve Gupta, 2017).

Taguchi Metodu, ortogonal dizileri kullanarak kontrol edilemeyen faktörlerin etkilerini minimize etmeye çalışan bir deneysel tasarım tekniğidir (Caniyılmaz, 2001). Ürünü üretmek için en iyi girdi kombinasyonunu belirlenen standartlaştırılmış bir yaklaşımdır. Taguchi yöntemi, tüm parametre uzayını yalnızca az sayıda deneyle incelemek için özel bir ortogonal dizi tasarımı kullanır (Lin, Chou ve Chou, 2007; Hsiao, Tarng ve Huang, 2008). Bu yöntemin en büyük avantajı, deneylerin yürütülmesinde harcanan çabadan tasarruf sağlamasıdır; deneysel zamandan tasarruf etme, maliyeti düşürme ve önemli faktörleri hızlı bir şekilde keşfetmektir. Taguchi yöntemi:

1. Kontrol edilebilir ürün tasarım faktörleri ile bir sürecin sonuçları arasındaki işlevsel ilişkiyi belirlemek için bir temeli,
2. Kontrol edilebilir değişkenleri optimize ederek bir sürecin ortalamasını ayarlamak için bir yöntemi,
3. Rastgele gürültü ile ürün değişkenliği arasındaki ilişkiyi incelemek için bir prosedürü sağlar (Deshmukh et al., 2013; Pan, 2004).

Proses parametrelerinin sayısı arttığında çok sayıda deneysel çalışma yapılması gerekmektedir. Bu sorunu çözmek için yöntemin en büyük avantajı, deneylerin yürütülmesinde harcanan çabadan tasarruf sağlamasıdır (Datta ve Mahapatra, 2010; Datta, Bandyopadhyay ve Kumar, 2007). Taguchi yöntemi adımları:

- Adım1:Önemlisüreçdeğişkenlerinin tanımlanması,
 Adım 2: Süreç planının geliştirilmesi,
 Adım 3: Plana göre deneylerin yapılması,
 Adım 4: Yanıtları kaydetme,
 Adım 5: Kaynaklı işin test edilmesi,
 Adım 6: Parametrelerin optimize edilmiş değerlerinin bulunması,
 Adım 7: Proses parametrelerinin ana ve önemli etkilerinin sunulmasıdır (Aytekin, 2011; Atar, 2021; Lin ve Chou, 2006; Lochner, 1990).

Demir, (2019) tarafından, "Projeksiyon kaynağı ile dual faz çeliğe cıvata kaynatılması ve Taguchi yöntemi ile parametre optimizasyonu" isimli yapılan çalışmada, öncelikle farklı parametreler herhangi sistematik kural olmadan denemeler yapılmış ve basma test sonuçları incelenmiştir. 3 farklı makine için yapılan testlerde optimuma yakın parametre aralıkları çıkarılmıştır. Bu süreçte çok fazla sayıda deneme parçası harcanmış, fazla zaman kaybı yaşanmıştır. Daha sonra sistematik yaklaşım sergilemek için Taguchi metodu kullanılmış ve ön analizlerde kullanılan parametreler limit değerler olarak belirlenmiştir. Taguchi metodu sayesinde çok düşük deneme adedi ile optimum parametre tespiti yapılmıştır. Bu sayede deneme parçalarının israfı da önlenmiştir. Taguchi metodunun sağladığı avantajlar değerlendirildiğinde fabrika proses iyileştirmelerinin

her alanında uygulanabileceği görülmüştür (Demir, 2019).

Kumanan ve Dhas (2011a), sürecin girdi-çıkı ilişkilerini kurmak için Taguchi'nin deney tasarımı ve regresyon analizini kullanmışlar. Bu ilişkiyle, optimal kaynak parametrelerini belirlemek için genetik algoritma (GA) ve parçacık sürüsü optimizasyonu (PSO) algoritmasına dayalı optimizasyon prosedürleri kullanılarak kaynak dikişi genişliği en aza indirilmeye çalışılmıştır. Sonuç olarak kaynak dikişi geometrisinin iyi bir göstergesi olarak tespit edilmiştir (Kumanan ve Dhas, 2011a).

Tarng ve arkadaşları tozaltı ark kaynağında proses parametrelerini belirlemek için Taguchi yöntemini kullanmışlardır. Bu yöntemin amacı, çok çeşitli kaynak kalitelerini de içerecek şekilde yeni bir çözüme ulaşmak olmuştur (Tarng, Juang ve Chang, 2002).

Akkaş yaptığı çalışmada, dikiş kalınlığının veya nüfuziyet alanının arzu edilen bir değeri için kaynak parametrelerinin alacağı değer teorik olarak belirlenmiştir. Teorik olarak elde edilen sonuçlarla deneysel sonuçlar karşılaştırıldığında, kaynak parametrelerinin dikiş kalınlığı için %98 ve nüfuziyet alanı için %99 doğrulukla tahmin edilebildiği görülmüştür. Bu çalışma tozaltı kaynağı için zeki kontrol sistemleri geliştirmeye yardımcı olabilmektedir. Geliştirilen sistem kullanılarak arzu edilen dikiş kalınlığı ve nüfuziyet alanı için kaynak parametreleri otomatik olarak seçilebilir. Bu durum, özellikle farklı kaynak kalınlıklarının söz konusu olduğu karmaşık yapıların tek operasyonla otomatik olarak kaynatılması hallerinde büyük önem taşımaktadır. Operasyon önceden hazırlanmış bir programla uygun bir nümerik kontrol sistemiyle denetlenebilmektedir. Böylece daha verimli ve kaliteli bir işlem gerçekleşmiş olmaktadır (Akkaş, 2006).

Ghosh ve diğerleri (2011), SAW prosesi tarafından üretilen kaynakta ve ısıdan etkilenen bölge (HAZ) ile ilgili belirsizliklerin sorununu ele almışlardır. En ilgi çekici konu, kaynaklı kalitede bazı belirsizlikler veren HAZ bölgesi ile ilgili olduğu görülmüştür. Kaynak bölgesinin ısıtma ve soğutma döngüsünün neden olduğu en zayıf bölgelerde yorulma arızası olasılığını artırdığını tespit etmişlerdir. Dijital görüntü işleme teknikleri aracılığıyla tane yapısının analizi yoluyla yapısal çelik plakaların tozaltı kaynağının ısıdan etkilenen bölgesi değerlendirilmiştir. Tanelerin ağırlıklı olarak daha küçük çeşitlilikte olduğu ve daha büyük tanelerin sayımlarının neredeyse ihmal edilebilir olduğu sonucuna varılmıştır. Görüntüde daha büyük boyutlu tanelerin olmaması, yapısal çelik levhaların rakip kaynak metodolojilerine kıyasla kaynağın sağlamlığını tespit etmişlerdir (Ghosh, Chattopadhyaya, ve Singh 2011).

Abdulbaset, Sonosi ve Abohusina (2022), kaynak dikişi geometri parametrelerinin kalitesi üzerindeki toz altı ark kaynağı (SAW) işlem değişkenlerini araştırmış ve optimum işlem değişkenlerini (akım (I), gerilim (V) ve hız (S)) olarak tanımlamışlar. ANOVA analiz sonuçları, kaynak akımının özellikle genişlik ve penetrasyon açısından kullanılan üç işlem değişkenden önemli ölçüde katkıda bulunduğunu ve bunu kaynak hızının izlediğini göstermiştir (Abdulbaset, Sonosi ve Abohusina, 2022).

Ghosh ve diğerleri (2011) tozaltı ark kaynağı verim parametrelerini tahmin etmek için grafik tekniği kullanmış ve ana faktörlerin etkisini yani akımın, tel besleme hızının, hareket hızının ve ana faktörler arasındaki etkileşimlerin kaynak dikişi parametreleri üzerindeki etkisini incelemişlerdir. Etkileşimler, sürecin önemli verim parametrelerine etki ettikleri görülmüştür (Chattopadhyaya, Ghosh, Das ve Sarkar, 2011).

2.2. Tozaltı Ark Kaynak Yöntemi (SWA)

Tozaltı kaynak işlemi, yüksek güvenilirlik, tam veya yarı otomatik uygulanabilirliği, derin nüfuziyeti ve düzgün bir kaynak dikişi elde edilebilirliği sebebi ile endüstride geniş uygulama alanına sahiptir (Karabulut, 2016). Kaynak değişkenlerinin bir kaynak bağlantısının kalitesini belirlemede önemli bir etkisi vardır. Bu nedenle optimum mekanik özelliklere sahip yüksek kaliteli kaynak özellikleri elde etmek için bu değişkenlerin stabilitesini incelemek esastır (Karaoğlu ve Seçgin, 2008). Bu değişkenler arasında akım, voltaj, hız, memeden plakaya mesafe, tel besleme hızı, akım tipi ve plaka kalınlığı bulunmaktadır (Jain, 2018; Choudhary, Kumar ve Unune, 2019; Vedrtam, Singh ve Kumar, 2018; Abohusina, 2018).

Reddy (2013), tozaltı ark kaynağında kaynak kalitesi, kaynak akımı, kaynak hızı, ark voltajı ve elektrot çıkıntısı gibi kaynak parametrelerinden büyük ölçüde etkilenir. Proses değişkenleri arasındaki ilişkiyi kurmak için deney tasarımı yapılmış ve en uygun çözümü bulmak için optimizasyon araçları kullanılmıştır. Kullanılan modüler ağ modelinde doğru veriler elde edilmiştir. Elde edilen analizler, kaynak genişliğinin kaynak akımına, kaynak takviyesinin ve kaynak sertliğinin elektrot çıkıntısına ve penetrasyon derinliğinin kaynak hızına bağlı olduğunu göstermiştir (Reddy, 2013).

Kumanan, Dhas ve Gowthaman (2007) tarafında yapılan çalışmada, kaynak deneylerinin ekonomik olarak araştırılması için deney tasarımında Taguchi yöntemi ile optimize edilmiştir. ANOVA'dan elde edilen sonuçlar, kaynak akımı ve ark voltajının, dikiş genişliğini etkileyen önemli kaynak işlemi parametreleri olduğunu göstermiştir. Matematiksel model, dikiş genişliği, dikiş takviyesi, penetrasyon derinliği ve dikiş sertliği için SPSS Paketi ile

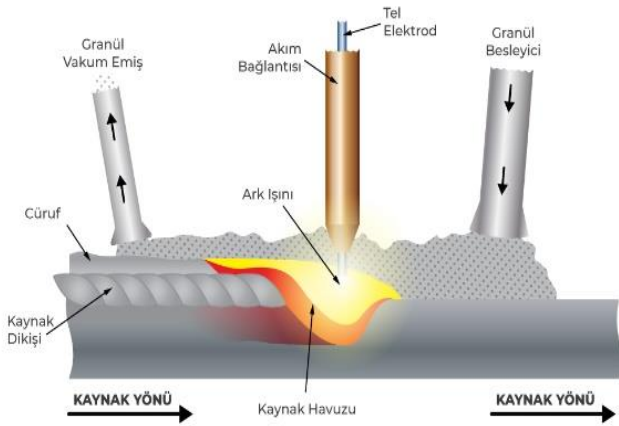
oluşturulmuştur. Öngörülen modelin çıktı sonuçları ilgili girdi verileri için hesaplanmıştır. Deneysel değerler ile tahmin edilen çoklu regresyon analizi modeli arasındaki dikiş genişliği, kaynak takviyesi, penetrasyon derinliği ve kaynak dikişi sertliği karşılaştırmaları arasında ilişki olduğu görülmüştür (Kumanan, Dhas ve Gowthaman, 2007).

Toz altı ark kaynağı, çoğu imalat endüstrisinde yaygın olarak kullanılan kaynak işlemidir. Sürekli beslenmeyen bir sarf malzemesi katı veya boru şeklinde elektrot gerektirir. Erimiş kaynak ve ark bölgesi, kireç, silika, manganez oksit, kalsiyum florür ve diğer bileşiklerden oluşan bir granül eriyebilir, akış örtüsü altına daldırılarak atmosferik kirlenmeden korunur. Eritildiğinde, akı iletken hale gelir ve elektrot ile iş arasında bir akım yolu sağlar. Bu kalın akı tabakası erimiş metali tamamen kaplar, böylece sıçrama ve kıvılcımların yanı sıra, Şekil 1'de gösterildiği gibi korumalı metal ark kaynağı (SMAW) işleminin bir parçası olan yoğun ultraviyole radyasyonu ve dumanları bastırır. Otomatik veya mekanize mod, bununla birlikte, basınçlı veya yerçekimi akı beslemeli yarı otomatik (el tipi) SAW tabancaları mevcuttur. Bu çalışmada yerçekimi akı beslemeli yarı otomatik SAW makinesi kullanılmıştır.

Karıştırıcı vidaların imalatında kullanılan parametrelerden biri de yaprakların mile kaynak yapılmasında kullanılan tozaltı ark kaynak yöntemi Şekil 1 ve Şekil 2'de gösterilmiştir. Toz altı kaynak yönteminde kaynak parametreleri (kaynak akımı, ark voltajı, tel ilerleme hızı, kaynak hızı, elektrot çıkıntısı, vb.) iyi seçildiği takdirde hatasız ve çok güzel görünümlü dikişler elde edilir. Normal örtülü elektrotla yapılan kaynağa göre bu yöntemde kullanılan aynı çaplı elektrot daha yüksek kaynak akımı ile yüklendiğinden, daha büyük kaynak banyosu ve daha derin nüfuziyet elde edilir. Yöntem, yarı otomatik ve tam otomatik kaynak uygulamalarına da müsait olduğu için, modern kaynak uygulaması olarak sanayileşmiş ülkelerde yaygın kullanım sahası bulmuştur (Akay, 2021; Kim, Young, Hwang, Kim ve Kim, 2001; Kaluç, 2004).



Şekil 1. Tozaltı ark kaynak yöntemi



Şekil 2. Tozaltı ark kaynak grafiği

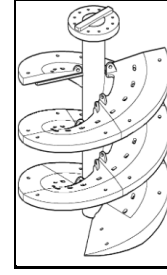
2.2.1. Tozaltı Ark Kaynak Yönteminin Avantajları

Tozaltı ark kaynak yöntemi, çok yüksek birikme oranına sahip yüksek kaliteli bir kaynak işlemidir. Genellikle düz pozisyonda kalın malzemeleri birleştirmek için kullanılır. Tamamen mekanize veya otomatik işlenmiş olarak çalıştırılır. Ancak yarı otomatik olarak da kullanılabilir. Kaynak işlemi sırasında operatör kaynak havuzunu gözlemleyemez ve kaynak işlemine doğrudan müdahale edemez. Kaynak prosesinde otomasyon arttıkça operatörün direkt etkisi azalmakta ve parametrelerin hassas olarak ayarlanması manuel kaynak proseslerinden çok daha önemli hale gelmektedir. Otomatik kaynak proseslerinde yüksek kalitede kaynak elde edebilmek için optimum parametrelerin seçimi mühendislik gerçeklerine göre yapılmalıdır (Çetinkaya, 2022; Anık, 1998; Külahlı, 1988).

Tozaltı ark kaynağı işlemi, istenen kaynak dikişi parametrelerine ve minimum bozulma ile mükemmel mekanik özelliklere sahip bir kaynaklı bağlantı elde eder. Kaynak değişkenlerinin, bir kaynak bağlantısının kalitesini belirlemede önemli bir etkisi vardır; bu nedenle, optimum mekanik özelliklere sahip yüksek kaliteli kaynak özelliklerine ulaşmak için bu değişkenlerin stabilitesini incelemek önemlidir. Bu değişkenler arasında akım, voltaj, hız, memeden plakaya mesafe, tel besleme hızı, akım türü ve plaka kalınlığı yer alır (Abdulbaset ve diğ., 2022).

Bu çalışmada Şekil 3'te gösterilen VTM karıştırma vidaları kullanılmıştır. Dikey karıştırıcı öğütücüler maden cevherlerinin öğütülmesinde ekonomik çözümler sunmaktadır. Bununla birlikte işleme zor kalın vida yaprağı ve dolu millerden üretilmeleri gerekmektedir.

Kaynak kullanımıyla beraber mil ile alaşımlı döküm vida yapraklarının birleştirilmesinde daha yüksek mukavemet ve rijitlik elde edilir. Dikey eksenli rulmanlı yataklama kullanılarak verimli çalışma sağlanır.



Şekil 3. Karıştırıcı vida

Aşınmaya dayanıklı alaşımlar ve paslanmaz çelikler gibi malzemeler yıllar içinde geliştikçe, karıştırma vidalarının kullanımı da endüstrinin birçok alanında kullanımı artmıştır. Üretim teknolojisindeki son gelişmeler, kaliteyi artıran ve maliyetleri azaltan belirli üretim süreçlerinin otomasyonunu içerir. Vida üretim sürecinde otomatik veya robotik kaynak kullanımı buna iyi bir örnektir.

Karıştırıcı vida yapımı için üretilen döküm yapraklar kanatlar uniform kalınlığa sahiptir. Vida yeterli sayıda profil kanadın döküm vida yaprağının merkez mil üzerine kaynatılması ile oluşturulur (Cema, 2003; Forcade, 1999; Nogay, 2007; Alışverişçi, 1985; Seshagiri ve Moorthi, 2015).

3. Yöntem

3.1. Çalışmada Kullanılan Yöntem ve Malzemeler

Bu çalışmada, bilimsel araştırma ve yayın etiğine uyulmuştur.

Hardox 400, (400HBW) nominal sertliğe sahip aşınmaya dayanıklı bir çelik malzeme kullanılmıştır. Esas olarak, aşınmaya maruz kalan yapılar, kazı, madencilik ve hafriyat makineleri, kamyon damperli gövdeler, taşıma, kırma ve toz haline getirme ekipmanları, hurda presleri ve kaldırım kalıpları alanlarında kullanılmaktadır. İşleme ve uygulama teknikleri bu çelikten imal edilen ürünlerin başarılı bir şekilde kullanılması için temel öneme sahiptir. Yüksek tokluğu, iyi bükülebilirliği ve kaynaklanabilirliği sayesinde bu çelik aşınmaya sahip yapılarda kullanılmaktadır.

Deney numuneleri Ankara'da bulunan Birikim Mühendislik Tasarım Merkezi'nde yapılmıştır. Firmanın özel olarak tasarlamış olduğu VTM Tozaltı Ark Kaynak Tezgâhında kaynak işlemleri yapılmış ve sonra deney numuneleri hazırlanmıştır. Tasarlanan bu tezgâhta, otomatik olarak vidaların aynı anda çift taraflı kaynak edilmesi gerçekleştirilmektedir. Yapılan deneysel çalışmaların sonuçları bu şekilde elde edilmiştir. Daha sonra elde edilen bu verilerin ışığında tozaltı ark kaynak işleminin Taguchi yöntemi ile eniyenmesi uygulaması için Minitab programında analizler elde edilmiştir.

Tablo 1.'de, tozaltı ark kaynak toz bileşenlerinin görevleri birbirinden farklı olup, tüm bileşenler farklı bir ihtiyaca göre karışıma katılmaktadır. Silisyum dioksit (SiO_2); asidik özelliğe sahip olup, viskozite ve ergime sıcaklığının ayarlanmasına yardımcı olmaktadır. Alüminyum oksit (Al_2O_3); doğal bileşen olup, cüruf oluşumunu sağlayarak, kaynak yapılabirliği kolaylaştırmaktadır. Ayrıca; viskozite ve ergime sıcaklığının ayarlanmasına yardımcı olmakta ve yüksek akımlarda arkın kararlılığını sağlamaktadır. Titanyum dioksit (TiO_2); asidik özelliğe sahip olup, cüruf oluşumunu başlatıcı bileşiktir. Cürufun kolayca kalkmasına yardımcı olmaktadır. Kalsiyum oksit (CaO); bazik özelliğe sahip cürufun viskozitesinin ayarlanmasına yardımcı olup kaynak metalinde oksijen miktarını azaltmaktadır. Kalsiyum florür (CaF_2); bazik özelliğe sahip, cürufun akışkanlığını iyileştirmekte, flor gazının oluşumunu sağlayarak ve kısmi buhar basıncını düşürerek kaynak metalindeki hidrojen miktarını azaltmaktadır. Mangan oksit (MnO); bazik özelliğe sahip

olup kaynak metalinin şeklini geliştirerek cürufun ergime sıcaklığı ve viskozitesinin ayarlanmasında etkilidir. Magnezyum oksit (MgO); bazik özelliğe sahip, ergimiş cürufun bazikliğini arttırmakta ve hidrojenin kaynak metalinden cürufa doğru ilerlemesini sağlamaktadır. Sodyum oksit (Na_2O) bu bileşik arkın kararlı olarak devam etmesinde önemli rol oynamaktadır (Davis, 1993).

Çalışmada kullanılan malzemeler Tablo 1.'de tozaltı ark kaynak makinesinde kullanılan kaynak tozlarının kimyasal analizleri, Tablo 2.'de tozaltı ark kaynak makinesinde kullanılan elektrotların kimyasal analizleri, Tablo 3.'te tozaltı ark kaynak makinesinde kullanılan milin kimyasal analizleri, Tablo 4.'te tozaltı ark kaynak makinesinde kullanılan yaprakların kimyasal analizleri, Tablo 5.'te gazaltı ve tozaltı ark kaynak makinesi kaynak parametreleri ve Tablo 6.'da kaynak dikişlerinin ölçülmesinde çıkan sonuçlar verilmiştir.

Tablo 1 .Tozaltı Ark Kaynak Makinesinde Kullanılan Kaynak Tozlarının Kimyasal Analizleri

Malzeme	Kimyasal Bileşim %								
	SiO_2	MnO	MgO	CaF_2	Na_2O	Al_2O_3	CaO	TiO_2	Metal alaşımı
FX860-25	19	11	17	12	2	32	2	2	3 max.

Tablo 2. Tozaltı Ark Kaynak Makinesinde Kullanılan Elektrotların Kimyasal Analizleri

Kullanılan elektrot	Kimyasal Bileşim								
	C	Mn	Si	P	S	Cr	Ni	Mo	Cu
AS S2	0,095	0,900	0,080	0,011	0,012	0,037	0,025	0,017	0,190

Tablo 3. Tozaltı Ark Kaynak Makinesinde Kullanılan Milin Kimyasal Analizleri

Malzeme	Kimyasal Bileşim										
	C	Mn	Si	P	S	Cr	Ni	Mo	Cu	Al	H(ppm)
ASTM A36	0,210	1,270	0,250	0,011	0,002	0,100	0,050	0,020	0,110	0,048	1,000

Tablo 4. Tozaltı Ark Kaynak Makinesinde Kullanılan Yaprakların Kimyasal Analizleri

Malzeme	Kimyasal Bileşim								
	C	Mn	Si	P	S	Cr	Ni	Mo	
ASTM A216 Grade WBC	0,189	1,001	0,475	0,015	0,013	0,116	0,001	0,002	

Tablo 5. Gazaltı ve Tozaltı Ark Kaynak Makinesi Kaynak Parametreleri

Paso Sayısı	Yöntem	Akımı (A)	Voltaj (V)	Kaynak Hızı (mm/dk)	Tel çapı (mm)	Akım tipi	Kaynak tozu/Gazı	Isı girdisi (KJ/mm)
1-2	135	258-260	28-29	10,21/124-135	1,2	DC(+)	M24	2,57-2,52
3-37	121	520-570	27,5-27,6	200-380	4,0	DC(+)	FX860-25	2,26-2,48
38-68	121	520-578	27,6	200-240	4,0	DC(+)	FX860-25	3,59-4,79

Tablo 6.'da VTM tozaltı helezon kaynak makinesi tezgâhında kaynak işlemleri yapılmış ve sonra deney numuneleri hazırlanmıştır. Tasarlanan bu tezgâhta


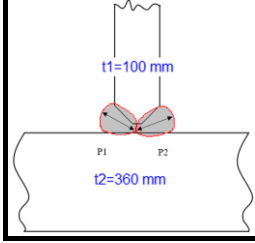
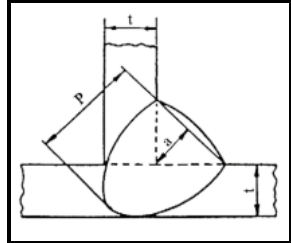
vidaların kaynak deney numuneleri Ankara'da bulunan Birikim Mühendislik Tasarım Merkezi'nde yapılmıştır. Tezgâhta, vidaların kaynak edilmesi aynı anda çift taraflı

otomatik olarak birleştirme işlemleri gerçekleştirilmiştir. Yapılan deneysel çalışmaların sonuçları bu verilerden elde edilmiştir. Daha sonra elde

edilen bu verilerin ışığında tozaltı kaynak işleminin Taguchi yöntemi ile en iyilenmesi uygulaması için Minitab programında analizleri yapılmıştır.

Tablo 6. Kaynak Dikişlerinin Ölçülmesinde Çıkan Sonuçlar

Kaynak Ölçüleri

Kaynak ölçüleri (mm), (Numune kalınlığı: t1=100/t2=360 mm)					
t1	t2	P1	P2	a1	a2
100	360	68	76	18	26

3.2. Taguchi Deney Tasarımı

3.2.1. Ortogonal Dizi ve Parametrelerin Seçilmesi

SAW kaynağında kaynak dayanımını direkt olarak etkileyen kaynak parametreleri;

1. Kaynak ilerleme hızı,
2. Kaynak akımı,
3. Gaz akış hızı,
4. Elektrot çapı
5. Elektrot çıkıntısı,
6. Isı girişi.

Yöntem olarak kaynak genişliği için Taguchi, ANOVA ve Regresyon analizi sırası ile kullanılmıştır. Taguchi, tercih edilen kalite karakteristiği olarak sinyal-gürültü (S/N) oranını kullanılmıştır. S/N oranı, standart sapma yerine ölçülebilir bir değer olarak kullanılır. ANOVA analizi, deneysel parametrelerin hangisinin en çok etkili olduğu ve modellemenin güvenliği için seçilmiştir. Regresyon analizi ise kaynak akımı, kaynak hızı, elektrot çıkıntısı ve ısı girişi ile kaynak dikiş nüfuziyetinin bağımlı değişkenleri arasındaki ilişkiyi belirlemek için çoklu regresyon analizi kullanılmıştır.

En basit hali ile S/N oranı, ortalamanın (sinyal) standart sapmaya (gürültü) oranıdır. S/N oranı; En büyük değer en iyi durumu için sinyal/gürültü oranını ifade eder (Eşme, 2006).

Bu çalışmada, kaynak nüfuziyeti kalite karakteristiği için "en büyük en iyi" (1, 2) denklem kriterleri kullanılmıştır.

$$\frac{S}{N}: -10 \log \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right) \quad (1)$$

Nominal en iyi olduğu durumda: kullanıldığı için aşağıdaki denklem uygulanmıştır.

$$\frac{S}{N}: 10 \log \left(\frac{\bar{y}}{s^2_y} \right) \quad (2)$$

Bu durumda, ikili toleransı olan bir karakteristik olduğunda nominal değer hedefdir. Yani bütün parçalar bu değere getirilirse, varyasyon sıfır olur ve en iyisidir. Hedef değer en iyi durumu için sinyal/gürültü oranını ifade eder. Kalite karakteristiği kategorisine bakılmaksızın, daha yüksek bir S/N oranı daha iyi kalite özelliklerine karşılık gelir. Bu nedenle proses parametrelerinin optimal seviyesi en yüksek S/N oranına sahip seviyedir (Montgomery, 1991; Gunaraj ve Murugan, 2000; Datta et. al., 2010).

Sinyal ve gürültü (S/N) oranı eniyilenmesi formülü (3) olarak tasarım yapılmıştır.

$$\frac{S}{N}: 10 \times \log_{10} \left(\frac{1}{n} \sum \left(\frac{1}{y^2} \right) \right) \quad (3)$$

Çalışmada yapılan analizdeki etkili faktörler Tablo 7.'de tanımlanmıştır. Her faktör için 2 seviye belirlenmiştir. Bilinen faktörlerin en iyi kombinasyonunu ve seviyelerini belirlemek için Taguchi yöntemi kullanılmış Minitab programı yardımıyla tasarlanmış ve analiz edilmiştir

Performans karakteristiğini etkileyecek faktör ve bunların seviyeleri Tablo 7.'de verilmiştir.

Tablo 7. Performans Karakteristikleri ve Faktör Seviyeleri

Malzeme	Kalınlık	Sembol	Kaynak Parametreleri	1. seviye	2. seviye
Hardox 400	16	A	Kaynak akımı (amp)	520	578
		B	Kaynak hızı	200	240
		C	Elektrot çıkıntısı	30	33
		D	Isı Girişi (KJ/mm)	3,59	4,79

Çalışmada L_8 ortogonal dizisi kullanılmıştır. Kullanılan dizinin serbestlik derecesi ise ($VL_8=8-1=7>9$) 7'dir. Ortogonal dizi $L_8 (2^7)$: 1 2 4 7 kullanılmıştır (Taguchi, 1989).

Tablo 8.'de 8 testin tümü gerçekleştirildikten sonra sonuçlar kaynak genişliği olarak ölçülmüştür. Her faktör için 2 seviye bulunmaktadır. Bilinen faktörlerin en iyi kombinasyonunu ve seviyelerini belirlemek için Taguchi yöntemi kullanılmıştır. Minitab programı yardımıyla tasarlanmış, analiz edilmiş ve sonuç L_8

olarak belirtilmiştir. Tablo 9.'da analizdeki etkili faktörler tanımlanmıştır.

Tablo 8. Deney Tasarımı

Taguchi Array	$L_8(2^4)$
Faktör	4
Runs	8

Tablo 9.'da tozaltı kaynak yöntemi ile yapılan deney numunelerinin nüfuziyet ölçüm değerleri sonuçları verilmiştir.

Tablo 9. Geleneksel Yöntemlerle Ölçülen Deney Girdileri ve Sonuçları

Deney No	A	B	C	D	
	Kaynak akımı (Amp)	Kaynak hızı (mm/dak)	Elektrod Çıkıntısı (mm)	Isı girişi (KJ/mm)	Kaynak genişliği (mm)
1	520	200	30	3.59	70
2	520	200	33	4.79	72
3	520	240	30	4.79	68
4	520	240	33	3.59	76
5	578	200	30	4.79	69
6	578	200	33	3.59	74
7	578	240	30	3.59	71
8	578	240	33	4.79	75

4. Bulgular

4.1. Kaynak Genişliği İçin Taguchi Analizi

Taguchi yöntemi ile analiz yapıldıktan sonra Tablo 10. ve Tablo 11.'de ki sonuçlar elde edilmiştir. Tablo 10. ve Tablo 11.'de gösterilen değerler, analizde büyük değer

daha iyi diye düşünülür. Bunun için her faktörde en büyük olan S/N oranı hangi faktörde hangi seviye en iyi sonucu verdiğini gösterir (Eşme, 2006). Bu sonuçlar incelendiğinde eniyilenmesi değerleri **A2B2C2D1**'de elde edilmiştir.

Tablo 10. S/N Oranı İçin Yanıt Tablosu

Seviye	Kaynak akımı (amp)	Kaynak hızı (mm/dak)	Elektrot çıkıntısı (mm)	Isı girişi (kj/mm)
1	37,08	37,05	36,84	37,23
2	37,17	37,20	37,41	37,02
Delta	0,09	0,15	0,57	0,21
Sıra	4	3	1	2

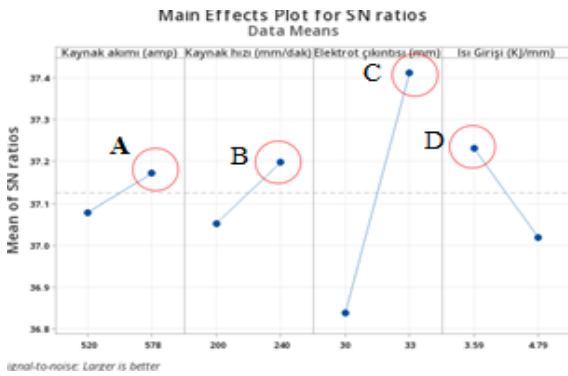
Tablo 11. Ortalama İçin Yanıt Tablosu

Seviye	Kaynak akımı (amp)	Kaynak hızı (mm/dak)	Elektrot çıkıntısı (mm)	Isı girişi (kJ/mm)
1	71,50	71,25	69,50	72,75
2	72,25	72,50	74,25	71,00
Delta	0,75	1,25	4,75	1,75
Sıra	4	3	1	2

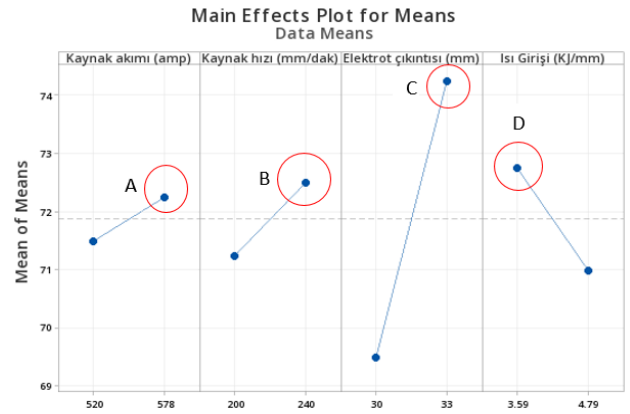
Şekil 4 ve Şekil 5'teki grafikler, yani ana etkiler grafikleri incelendiği zaman, seçilen kaynak parametrelerinden 'elektrot çıkıntısı'nın SN oranı üstünde ve ortalama kaynak dikiş genişliği üzerinde en büyük etkiye sahip olduğu görülmektedir.

Taguchi yönteminde sonuçları analiz etmek için, sinyal gürültü oranı (S/N) adı verilen istatistiksel bir performans ölçüsü kullanılır. S/N oranı, ortalamayı ve değişkenliği hesaba katar ve optimize edilecek kalite karakteristiğinin kriterlerine bağlıdır (Konishi ve Taguchi, 1987). Sinyal/Gürültü oranının hesaplanmasında deneyler sonucu ulaşılması hedeflenen kalite değerinin özelliği de önemlidir.

p-değeri (örneğin, $\alpha=0,05$), belirli bir eşik değerinin altında ise, ANOVA hipotezini reddetmek ve grup ortalamaları arasında istatistiksel olarak önemli bir fark olduğu sonucuna varabiliriz. Tablo 14'te de $p= 0,008$ elektrot çıkıntısı olarak bulunmuştur. Şekil 4 ve Şekil 5'teki grafikler incelendiği zaman seçilen kaynak parametrelerinin kaynak dikiş genişliği üzerinde kuvvetli etkisi olduğu görülmektedir.

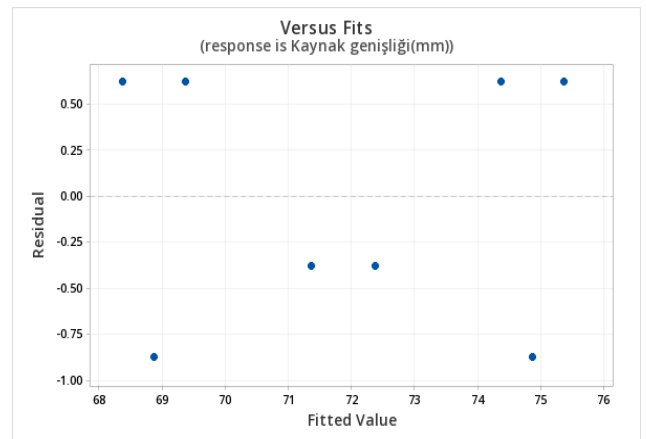


Şekil 4. Sinyal-Gürültü (S/N) oranı grafiği

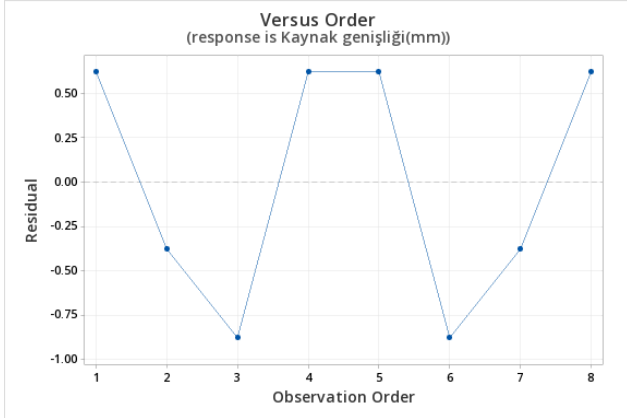


Şekil 5. Ortalama değer grafiği

Şekil 6 ve Şekil 7'de bir artık analizi yapılırken, en sık oluşturulan çizim bir "artıklar ve uyanlar grafiği"dir. Bu, y ekseninde artıkların ve x ekseninde uydurulmuş değerlerin (tahmini tepkiler) bir dağılım grafiğidir. Grafik, doğrusal olmayan, eşit olmayan hata varyansları ve aykırı değerleri tespit etmek için kullanılır. Artıkların rastgele dağıldığı ve sabit varyansa sahip olduğu varsayımını doğrulamak için artıklara karşılık uygun grafiği kullanılır. İdeal olarak, noktalar 0'ın her iki tarafına rastgele düşmelidir ve noktalarda tanımlanabilir desenler olmamalıdır.



Şekil 6. Kaynak genişliği için uygunluklar



Şekil 7. Kaynak genişliği için güven ve tahmini aralıklar

4.2. Kaynak Genişliği İçin Genel Doğrusal Model (ANOVA):

ANOVA analizi deneysel parametrelerin hangisinin en çok etkili olduğunu ve modellemenin güvenliğini gösterir. Bunun için Tablo 12’de yöntem ve Tablo 13’te faktör bilgileri verilmiştir.

Tablo 14. Varyans Analizi

Kaynak	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Kaynak akımı(amp)	1	1,125	1,91%	1,125	1,125	1,00	0,391
Kaynak hızı(mm/dak)	1	3,125	5,31%	3,125	3,125	2,78	0,194
Elektrot çıkıntısı(mm)	1	45,125	76,65%	45,125	45,125	40,11	0,008
Isı girişi(kj/mm)	1	6,125	10,40%	6,125	6,125	5,44	0,102
Error	3	3,375	5,73%	3,375	1,125		
Total	7	58,875	100,00%				

DF(DOF): Serbestlik derecesi.

Seq Ss: Sequential sum of squares: Modelin farklı bileşenleri için varyasyon ölçüsü.

Contribution: Her faktörün katkı yüzdesini göstermektedir. Bu analizde C (Elektrot çıkıntısı), D (Isı girişi), B (Kaynak hızı) ve A (Kaynak akımı) yani en çok katkısı olan faktör elektrot çıkıntısı ve en az katkısı olan kaynak akımı olduğu görülmektedir.

F-Value: F değeri hesaplanması: Numune ortalamaları arasındaki varyasyon/numuneler içindeki varyasyon; $40,11=45,125/1,125$ değer çıkmıştır.

F değeri ne kadar yüksek olursa, numuneler içindeki varyasyona göre numune ortalamalar arasındaki varyasyon o kadar yüksek olur.

F değeri ne kadar yüksek olursa, karşılık gelen p değeri o kadar düşük olur.

p-değeri (örneğin, $\alpha=0,05$), belirli bir eşik değerinin altında ise, ANOVA hipotezini reddetmek ve grup ortalamaları arasında istatistiksel olarak önemli bir fark olduğu sonucuna varılabilir. Tablo 14’te de $p=0,008$ çıktı üzerinde %5 anlam düzeyinde anlamlı etkiye sahip olan

Tablo 12. Yöntem

Faktör kodlaması: (-1; 0; +1)

Tablo 13. Faktör Bilgileri

Faktör	Tip	Seviyeler	Değerler
Kaynak akımı(amp)	Fixed	2	520; 578
Kaynak hızı(mm/dak)	Fixed	2	200; 240
Elektrot çıkıntısı(mm)	Fixed	2	30; 33
Isı girişi(kj/mm)	Fixed	2	3,59;4,79

Tablo 14’te ise varyans analiz değerleri görülmektedir.

tek parametrenin elektrot çıkıntısı olduğu görülmektedir.

R-sq (R²), model tarafından açıklanan yanıtta varyasyon yüzdesidir. 1 eksi kareler hata toplamının (model tarafından açıklanmayan varyasyon) toplam kareler toplamına (modeldeki toplam varyasyon) oranı olarak hesaplanır. Modelin güvenilirliği Tablo 15’te %94,27 gibi yüksek bir değer çıkmıştır. Çıkan bu değer de modelin uygulanabileceğini göstermektedir.

Tablo 15. Model Özeti

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)
1,06066	94,27%	86,62%	24	59,24%

4.3. Kaynak Genişliği İçin Regresyon Analizi

Kaynak akımı, kaynak hızı, elektrot çıkıntısı ve ısı girişi ile kaynak dikiş nüfuziyetinin bağımlı değişkenleri arasındaki ilişkiyi belirlemek için çoklu regresyon analizi kullanılmıştır. Regresyon analizi Minitab 18

yazılımı ile yapılmıştır. Giriş parametrelerinin regresyon analizi Tablo 16.'da doğrusal denklemde ifade edilmiştir.

Elde edilen regresyon denklemi ile öngörülen kaynak genişliği Tablo 17.'de hesaplanmıştır.

Tablo 16. Regresyon Denklemi

$$\text{Kaynak genişliği (mm)} = 1.583 * \text{Elektrot çıkıntısı (mm)}$$

Tablo 17. Katsayılar

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Sürekli	14.1	11.7	(-23.0, 51.3)	1.21	0.313	
Kaynak akımı (amp)	0.0129	0.0129	(-0.0282, 0.0541)	1.00	0.391	1.00
Kaynak hızı (mm/dak)	0.0313	0.0187	(-0.0284, 0.0909)	1.67	0.194	1.00
Elektrot çıkıntısı (mm)	1.583	0.250	(0.788, 2.379)	6.33	0.008	1.00
Isı Girişi (KJ/mm)	-1.458	0.625	(-3.447, 0.531)	-2.33	0.102	1.00

Tablo 18.'de model özeti, Tablo 19.'da varyans analizi ve Tablo 20.'de ise öngörülen kaynak genişliği değerleri verilmiştir.

Tablo 18. Kaynak Genişliği Model Özeti

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
1.06066	94.27%	86.62%	24	59.24%	111.80	28.28

Tablo 19. Kaynak Genişliği Varyans Analizi

Kaynak	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regresyon	4	55.500	94.27%	55.500	13.875	12.33	0.033
Kaynak akımı (amp)	1	1.125	1.91%	1.125	1.125	1.00	0.391
Kaynak hızı (mm/dak)	1	3.125	5.31%	3.125	3.125	2.78	0.194
Elektrot çıkıntısı (mm)	1	45.125	76.65%	45.125	45.125	40.11	0.008
Isı Girişi (KJ/mm)	1	6.125	10.40%	6.125	6.125	5.44	0.102
Error	3	3.375	5.73%	3.375	1.125		
Total	7	58.875	100.00%				

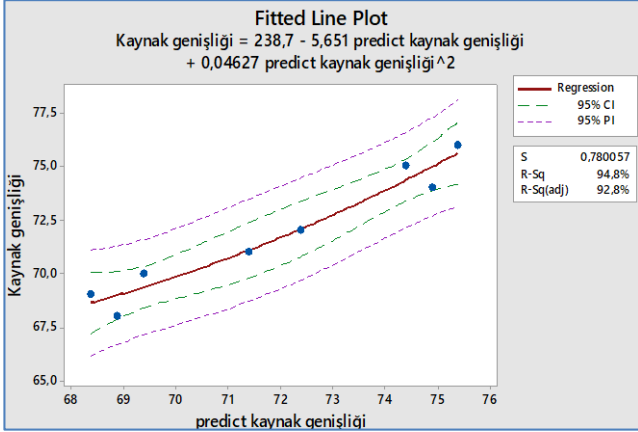
Tablo 20. Öngörülen Kaynak Genişliği Değerleri

Deney No	A	B	C	D	E	F
	Kaynak akımı(amp)	Kaynak hızı(mm/dak)	Elektrot çıkıntısı(mm)	Isı girişi(Kj/mm)	Kaynak genişliği	Öngörülen kaynak genişliği
1	520	200	30	3.59	70	69,375
2	520	200	33	4.79	72	72,375
3	520	240	30	4.79	68	68,875
4	520	240	33	3.59	76	75,375
5	578	200	30	4.79	69	68,375
6	578	200	33	3.59	74	74,875
7	578	240	30	3.59	71	71,375
8	578	240	33	4.79	75	74,375

Şekil 8'de güven aralıkları ve tahmin aralıkları görülmektedir. Burada;

PI: Tahmini değerlerin sınırı,

CI: Güven aralığıdır.



Şekil. 8 Güven aralıkları ve tahmini aralıklar

Şekil 8'de görüldüğü gibi mavi çizgiler (deneyler) regresyon çizgisine (kırmızı) ne kadar yakın olursa R-sq yani bağımsız değişkenden tahmin edilebilen bağımlı değişkendeki varyasyonun oranı da o kadar yüksek olur.

5. Sonuçlar ve Tartışma

Bu çalışmada, sinyal-gürültü oranı (S/N) grafiğinde en çok etkileyen faktörler elektrot çıkıntısı ve ısı girişidir. Deneyleri en az etkileyen ise kaynak akımı ve kaynak hızıdır. Analizde büyük değer daha iyi diye düşünüldüğü için her faktörde en büyük olan S/N oranı hangi faktörde hangi seviye en iyi sonucu verdiğini gösterir. Kaynak genişliğine göre S/N oranının cevabı, kaynak genişliğini kontrol eden en önemli parametrenin elektrot çıkıntısı olduğu görülürken, diğer parametreler bu açıdan nispeten daha az önemlidir. Bu sonuçlar incelendiğinde eniyilenmesi değerleri A2B2C2D1'de elde edilmiştir. Kaynak akımı (37,17), Kaynak hızı (37,20), elektrot çıkıntısı (37,41) ve Isı girişi (37,23) değerleri tespit edilmiştir.

Taguchi yöntemi, proses parametrelerini basit bir şekilde basitleştirmek için etkili bir yöntem olarak bulunmuştur. Bu nedenle kalite iyileştirme ve kalite çözümlerinde kullanılabilir. Tam faktöriyel analiz ile güvenilir ve basit bir doğrulama yöntemi olan bu yöntem diğer tüm çalışmalarda önerilebilir.

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RECYCLING OF IRON AND STEELMAKING PLANTS WASTES

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Keywords	Abstract
Waste-recycled, sulphur removal, magnetic separation, steelwork wastes utilization, statistical experimental design.	As a result of the processes applied in the steel production, approximately 400 kg of waste is generated for every one ton of steel products. According to environmental regulations, these wastes must be disposed or stored in waste dams, which imposes a serious financial burden on iron and steel enterprises. In recent years, wastes with a high iron content has been recovered and returned to the steelmaking processes, replacing ore and contributing to a more efficient use of resources. However, despite the high iron content, it is not possible to use high sulphur content wastes as raw material in steel production. In this study, it is aimed to increase the utilization possibilities of these wastes as secondary raw material by reducing the content of sulphur in the concentrate by magnetic separation. It was shown that 33.34% of the wastes can be recycled with 54.90% iron recovery and 74.43% sulphur removal after dry magnetic separation experiments while 14.66% of the wastes can be recycled with 28.60% iron recovery and 89.93% sulphur removal after wet magnetic separation experiments. These removals correspond to 0.03% and 0.01% sulphur contents in the concentrates after dry and wet magnetic separations, respectively, and the concentrates can be blended back into the main raw material.

DEMİR ÇELİK TESİS ATIKLARININ GERİ DÖNÜŞÜMÜ

Anahtar Kelimeler	Öz
Atık geri dönüşümü, kükürt giderme, manyetik ayırma, çelik atıkları kullanımı, istatistiksel deneysel tasarım.	Çelik üretiminde uygulanan işlemler sonucunda her bir ton çelik ürün için yaklaşık 400 kg atık oluşmaktadır. Çevre mevzuatına göre bu atıkların bertaraf edilmesi veya atık barajlarında depolanması gerekmektedir ki bu da demir-çelik işletmelerine ciddi bir mali yük getirmektedir. Son yıllarda demir içeriği yüksek atıkların geri kazanılması ile cevherin yerini alacak şekilde çelik üretim proseslerine geri döndürülmekte ve böylece kaynakların daha verimli kullanılmasına katkı sağlanmaktadır. Ancak yüksek demir içeriğine rağmen yüksek kükürt içeriğine sahip atıkların çelik üretiminde hammadde olarak kullanılması mümkün değildir. Bu çalışmada manyetik ayırma ile konsantredeki kükürt içeriğinin azaltılması ile bu atıkların ikincil hammadde olarak kullanım olanaklarının artırılması amaçlanmaktadır. Kuru manyetik ayırma deneyleri sonrasında atıkların %33,34'ünün %54,90 demir geri kazanımı ve %74,43 kükürt giderimi ile geri dönüştürülebileceği, yaş manyetik ayırma sonrası atıkların %14,66'sının %28,60 demir geri kazanımı ve %89,93 kükürt giderimi ile geri dönüştürülebileceği gösterilmiştir. Kuru ve yaş manyetik ayırmalardan sonra elde edilen konsantrelerin kükürt içerikleri sırasıyla %0,03 ve %0,01 olup, bu konsantreler tekrar ana hammaddeye harmanlanabilir niteliktedir.

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1. Introduction

The iron and steel industry create output and employment in hundreds of other industries all over the world. Considering all of the industries with direct, indirect and induced impacts, the steel industry offers more than \$ 1,000 billion in economic output and nearly six million jobs. Steel is found utilization in a very large industrial sectors including automotive, construction, packaging and rail sectors without which modern society cannot remain sustainable. World crude steel production reached 1689.4 million tonnes (Mt) for the year 2017, up by 3.8% compared to 2016. The biggest steel producer country is China, and its crude steel production in 2017 is 831.7 Mt accounting for 49.2% of the world. Ranking 8th in the world total steel production with a share of 2.2%, Turkey's steel production in 2017 was 37.5 million tons of crude steel, with an increase of approximately 13% compared to the previous year. (Basson, 2018)

There are two main processes for crude steel production: blast furnace - basic oxygen furnace (BF-BOF) and electric arc furnace (EAF) routes. Besides these two main routes, there are other routes such as open heart furnaces (OHF) used in steelmaking in Russia and Ukraine. 71.5% of the world's crude steel production is via BF-BOF route while 28% of that via EAF production route. The other methods are negligible and accounts for only 0.5% of total production (Basson, 2018). It was claimed that on average, solid wastes of 200 kg for the electric arc furnace (EAF) route and 400 kg for the blast furnace - basic oxygen furnace (BF-BOF) route were produced for the manufacture of one ton of steel (Worldsteel Association, 2018). The main solid wastes produced during crude steel production are slags (90% by mass), dust and sludge. These wastes are disposed or dumped to the waste dams which causes serious negative environmental impact as well as financial burden on the iron and steel industry. On the other hand, the World's economy currently loses a significant amount of potential secondary raw materials which are found in waste streams. It was reported that total solid waste generation in 2013 in the EU was about 2.5 billion tons of which less than 1 billion tons were reused or recycled therefore enormous amount of lost for the European economy was recorded. (European Commission 2015). Furthermore, EU published a directive on 30 May 2018 on the subject which states that "Waste management in the Union should be improved and transformed into sustainable material management, with a view to protecting, preserving and

improving the quality of the environment, protecting human health, ensuring prudent, efficient and rational utilisation of natural resources, promoting the principles of the circular economy, enhancing the use of renewable energy, increasing energy efficiency, reducing the dependence of the Union on imported resources, providing new economic opportunities and contributing to long-term competitiveness. In order to make the economy truly circular, it is necessary to take additional measures on sustainable production and consumption, by focusing on the whole life cycle of products in a way that preserves resources and closes the loop" (European Commission 2018). According to the EU waste hierarchy, in waste management, the first priority is given to waste prevention, then to recycling, then to energy recovery and finally to disposal.

In this study, the utilization possibilities of BOF slags as a secondary raw material, taken from an iron and steel plant's waste landfills were investigated by decreasing sulphur content by dry and wet magnetic separation methods. Central Composite Design (CCD) which is one of the statistical experiment design methods was used to design magnetic separation experiments (Khuri and Mukhopadhyay, 2010). Iron recovery, sulphur removal rate and weight yield of the concentrate were accepted as dependent variables (response variables). After variance analysis, regression models were created for each dependent variable by using Stat-Ease Design Expert software version 11.

2. Scientific Literature Review

Over the past 20 years, the use of the steel industry's wastes has increased significantly. The recovery of high iron content wastes and their return to steel production processes instead of ore contributes to the more efficient use of resources. Other wastes have many uses in other industries; For example, while steelmaking slags are used as aggregates in road construction, blast furnace slags and dust are used in cement production instead of clinker (Worldsteel Association, 2018).

In Turkey, a number of steel production plants operating by basic oxygen furnace route are distributed mainly north-west part of Turkey. 420 kg of solid wastes are produced for each ton of steel production, and these solid wastes include mainly BOF slags, dust and sludge wastes. These wastes are disposed to nearby landfills that cause severe environmental problems, and only a small percentage is recycled (Alanyalı, Çöl, Yılmaz and

Karagöz, 2006; Lan, Liu, Meng, Niu and Zhao, 2017). In this respect, BOF slags with as much as 14-20% iron content (Ocal, 2014) are important and can be utilized as secondary source for steel production. However, the impurities such as sulphur and improper particle sizes limit their utilization as secondary raw materials. The use of these slags can be increased by removing the unwanted impurities to an acceptable level by means of concentration methods. These methods include crushing, sizing, magnetic separation, flotation and leaching (Li, 1999; Shen and Forsberg, 2003; Alanyali, et al. 2006; Bilen, 2010; Menad, Kanari and Save, 2014; Ma and Houser, 2014; Lan, et al. 2017).

3. Materials and Methods

3.1. Materials

Basic oxygen furnace slags taken from an iron and steel production plant’s waste landfills were used throughout the experimental work. The slags contained 18.33% Fe, %0.15 S, %0.56 P and %39.61 Ca. The samples were crushed to -1 mm with a jaw crusher and sieved into three size fractions: -1+0.3; -0.3+0.075; -0.075 mm. In this article, the results of the studies with -0.3 + 0.075 mm size fraction suitable for both wet and dry magnetic separation are given; experimental results of other size fractions where only wet or dry magnetic separation or other methods were studied are not given here. The studied fraction represents 46.57% of the total sample by weight. The chemical composition of the studied sample determined by XRF analysis (by Panalytical ZETIUM) and contained 18.62% Fe, %0.13 S, %0.66 P and %41.53 Ca.

Figures 1 (a) and (b) show the XRD (by Panalytical EMPYREAN) and SEM-EDS (by Hitachi Regulus 8230 FE-SEM) patterns of studied sample. In the XRD pattern, iron, calcium and sulphurous compounds are observed. Although phosphorus was not seen in the XRD pattern, low content of phosphorus was detected by XRF analysis. XRD and SEM-EDS patterns proved that Portlandite (Ca(OH)₂), Larnit (2CaOSiO₂), Brownmillerite (Ca₂(Al,Fe)₂O₅), Vustit (FeO), Calcite (CaCO₃), Magnetite (Fe₃O₄), Lime (CaO) were present in the sample. As it can be observed from Figure 1 that the peaks in the EDS pattern and the peaks in the XRD graphs overlap and indicate the same minerals. The SEM images also show that these minerals are locked with each other and difficult to be liberated even by fine grinding.

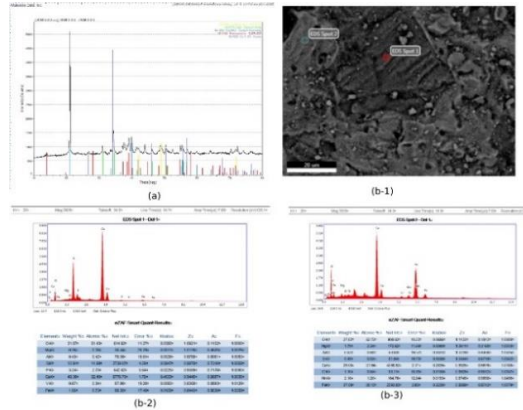


Figure 1. XRD (a) and SEM-EDS (b) Patterns of Studied Sample

3.2. Methods

Two different laboratory size magnetic separators, dry and wet type, were used to increase iron content and to decrease sulphur content of the studied material. Carpco Laboratory High-Intensity Induced-Roll Magnetic Separator which is a free fall type separator produced by Outokumpu Technology, Inc was used as dry magnetic separator. Its magnetic field strength is adjustable between 0 to 20 kilo gauss.

Master Magnet M5695 model laboratory type wet magnetic separator was utilized in the wet magnetic separation experiments. Pulp is fed manually to the magnetic separator which has three magnetic matrixes. The magnetic field strength can be set up to 25 kilo gauss from the control unit. The current intensity (ampere) can be adjusted in the device used, and the voltage intensity (volt) is read from the panel. The magnetic field strength was calculated by using the tension-generated magnetic field (gaussian) relationship given in the user manual of the device.

In the experimental studies, the effects of magnetic field strength, feed rate and drum rotational speed on dry magnetic separation (DMS) were examined while the effects of magnetic field strength, feed rate and solid ratio were examined on wet magnetic separation (WMS) as independent variables (parameters). After each magnetic separation experiments, two products were obtained: magnetics and non-magnetics. Magnetics fraction was called as concentrate while non magnetics as tailings. Iron and sulphur content of the concentrate and tailings were analysed by XRF, and iron recovery (R Fe, %), sulphur removal rate (S_{Rem}, %) and weight yield (WY, %) as dependent variables (response variables) were calculated from the equations 1 to 3 as given below:

$$R_{Fe} (\%) = \frac{C \cdot c_{fe}}{F \cdot f_{fe}} * 100 \tag{1}$$

$$S_{Rem} (\%) = \frac{F \cdot f_s - C \cdot c_s}{F \cdot f_s} * 100 \tag{2}$$

$$WY (\%) = \frac{C}{F} * 100 \tag{3}$$

where, *C* and *F* are the amounts of concentrate and feed, respectively; *c_{fe}* and *c_s* are the iron and sulphur contents of concentrate, respectively; *f_{fe}* and *f_s* are the iron and sulphur contents of feed, respectively. Stat-Ease Design Expert software version 11 was used for statistical design and to obtain mathematical models of the response variables. Due to the design features of the magnetic separators used and in terms of practicality in setting the parameters, the alpha (α) coefficient used in the calculation of the axial points in dry and wet magnetic separations is taken as 1.4 and 2, respectively. In this study, independent variables (parameters) and their levels are given in Table 1 for dry and wet magnetic separation experiments. The levels for the factors were determined by preliminary experiments.

Table 1

Independent Variables and Levels for Magnetic Separation Experiments

Independent Variables (Parameters)						
DMS		Levels				
Fac.	Unit	-α	-1	0	1	+α
A	Gauss	20	100	300	500	580
B	g min ⁻¹	82	90	110	130	138
C*	rpm	4	10	25	40	46
WMS		Levels				
A	10 ³ Gauss	2.5	10.6	14.3	14.7	14.8
B	g min ⁻¹	10	15	20	25	30
C**	%	3	6	9	12	15

A: Magnetic field strength; B: Feed rate; C*: Drum rotational speed; C**:Solid ratio

4. Results and Discussion

The number of experiments with axial points in CCD was planned as 20 experiments for 3 parameters. All experiments were carried out randomly, and the results are given in Table 2.

As can be seen from Table 2, iron recovery, sulphur removal and weight yield were obtained as 54.90%, 74.43% and 33.47%, respectively at experiment 7 (100 Gauss, 130 g min⁻¹, 40 rpm) for DMS experiments. Iron recovery, sulphur removal and weight yield were obtained as 28.60%, 89.93% and 14.66%, respectively at experiment 9 (2500 Gauss, 200 g min⁻¹, 9%) for WMS experiments. Although iron recovery seemed to be low at wet magnetic separation experiments, sulphur removal was obtained as nearly 90% which makes the BOF slags suitable for recycling.

Table 2. Design Matrix and Results of DMS and WMS Experiments

No	Coded values of factors			Dry Magnetic Separation			Wet Magnetic Separation		
	A	B	C	R _{Fe} (%)	S _{Rem} (%)	WY (%)	R _{Fe} (%)	S _{Rem} (%)	WY (%)
1	-1	-1	-1	65.43	57.27	50.60	75.67	41.33	58.30
2	1	-1	-1	89.97	16.83	25.92	94.63	6.84	88.89
3	-1	1	-1	60.14	60.11	45.60	75.60	41.69	23.29
4	1	1	-1	88.89	22.34	81.49	96.72	16.74	87.80
5	-1	-1	1	57.68	71.53	37.07	66.02	48.32	49.57
6	1	-1	1	84.63	27.86	25.68	97.36	11.60	91.14
7	-1	1	1	54.9	74.43	33.47	68.05	45.81	52.27
8	1	1	1	85.71	27.09	77.60	97.03	13.51	91.07
9	-α	0	0	43.16	72.33	27.06	28.60	89.93	14.66
10	+α	0	0	92.75	12.84	65.90	98.77	5.87	94.64
11	0	-α	0	86.87	24.11	78.96	90.52	13.34	83.21
12	0	+α	0	91.36	20.00	80.24	95.51	14.24	86.04
13	0	0	-α	54.37	59.29	42.40	95.16	26.58	85.71
14	0	0	+α	53.43	45.21	44.22	92.80	16.36	84.44
15	0	0	0	87.04	16.41	59.36	86.88	31.75	69.55
16	0	0	0	89.04	15.32	78.87	89.30	22.50	79.39
17	0	0	0	91.14	39.02	89.12	96.11	19.98	82.66
18	0	0	0	84.62	18.66	68.96	92.46	17.90	82.44
19	0	0	0	91.54	20.94	81.80	88.91	23.72	78.24
20	0	0	0	86.29	26.03	73.58	76.55	28.76	73.76

The experimental results were subjected to variance analysis for three response variables (iron recovery, sulphur removal rate and weight yield). As a result of variance analysis, the regression models were created for coded factors. Reduced ANOVA tables were prepared by eliminating statistically insignificant terms from the model with 95% confidence interval.

There are two main indicators that determine the effectiveness of a model: the coefficient of determination (R^2) and predicted R^2 (P- R^2). The consistency of a model with experimental data is represented by R^2 value which is the proportion of the variance in the dependent variable. Further, the power of a model is determined by P- R^2 which is a measure of how well the model predicts a response value (Khuri and Mukhopadhyay, 2010) Both indicators are also presented at the reduced ANOVA tables. The results were also examined by graphically. Reduced ANOVA result for dry and wet magnetic separation experiments are given in Table 3 for three response variables according to magnetic separation experimental results. Statistically insignificant terms were eliminated from the models with 95% confidence interval.

4.1. Dry Magnetic Separation (DMS) Experiments

According to ANOVA results of DMS, three regression models were created for iron recovery, sulphur removal rate and weight yield, and given in equations 4-6, respectively. Proposed models by software for all three response variables are significant as p values of models are less than 0.05. p values of Lack of fit for all models are greater than 0.05 which indicates experimental error is statistically insignificant.

$$RFe (\%) = 88.12 + 13.14 A + 0.057 B - 1.46 C - 5.23 A^2 - 8.74 C^2 \tag{4}$$

$$SRem (\%) = 25.33 - 18.01 A + 0.14 B + 1.01 C + 5.70 A^2 + 8.11 C^2 \tag{5}$$

$$WY (\%) = 72.52 + 7.60 A + 6.34 B - 1.63 C + 14.51 AB - 8.43 A^2 - 9.22 C^2 \tag{6}$$

The R^2 values are obtained as 0.9789, 0.8454 and 0.7571 for R_{Fe} , S_{Rem} and WY, respectively (Table 3). Graphical representation of predicted results versus actual results for all three response variables are given in Figs. 2 (a-c). As can be seen from the graphs, the R_{Fe} , S_{Rem} , and WY values estimated from the models represent the experimental results by approximately 98%, 85% and 76%, respectively which indicates the high consistency of the model for R_{Fe} and S_{Rem} while relatively the low consistency of the model for WY.

Table 3. The Results of Analysis of Variance (reduced ANOVA) for Three Response Variables for DMS and WMS

DMS		R_{Fe} (%)	S_{Rem} (%)	WY (%)
p Values	Model	<0.0001	<0.0001	0.0020
	A	<0.0001	<0.0001	0.0354
	B	0.9369	0.9551	0.0720
	C	0.0571	0.6873	0.622
	AB	-	-	0.0074
	A ²	<0.0001	0.0102	0.0053
	B ²	-	-	-
	C ²	<0.0001	0.0008	0.0029
	Lack of fit	0.5019	0.3790	0.2515
	Std. D.	2.82	9.86	12.95
R^2	0.9789	0.8454	0.7571	
P R^2	0.9376	0.4224	0.2337	
WMS		R_{Fe} (%)	S_{Rem} (%)	WY (%)
p Values	Model	<0.0001	<0.0001	<0.0001
	A	<0.0001	<0.0001	<0.0001
	B	0.5391	0.5903	0.4309
	C	0.4000	0.7133	0.5092
	A ²	<0.0001	<0.0001	0.0008
	B ²	-	0.0369	-
	C ²	-	-	-
	Lack of fit	0.8270	0.5481	0.0813
	Std. D.	5.45	5.20	8.59
	R^2	0.9162	0.9476	0.8835
P R^2	0.8043	0.8561	0.7663	

As can be seen from Table 3, the P- R^2 values are obtained as 0.9376, 0.4224 and 0.2337 for R_{Fe} , S_{Rem} and WY, respectively. These figures indicate high power for R_{Fe} while relatively low power for S_{Rem} and WY in comparison with R_{Fe} .

In a statistical design, factors that cause variability in the performance of a system but cannot be controlled called as noise factors (Steinberg and Bursztyn, 1998). It is noteworthy to point out that the weakest model obtained in the experiments is the model created for weight yield in dry separation. The correlation coefficient of this model was 75.71%. The main reason for this is thought to be the high amount of magnetic clustering. This is a noise factor in the system and causes uncontrolled fluctuation in the amount of material coming to the magnetic product. The high correlation coefficients of the models obtained in iron recovery and sulphur removal in dry separation indicate that the selectivity could be maintained somewhat despite magnetic clustering.

The main effects of parameters on R_{Fe} (%), S_{Rem} (%) and

WY (%) are given in Figs. 2 (d-f), respectively. As it can be seen from the ANOVA Table (Table 3) and Figs. 2 (d-f), the most effective parameter for all response variables is the magnetic field strength (A). Both linear and quadratic effects of magnetic field strength are found to be significant for all response variables. Linear effects of feed rate (B) and drum rotation speed (C) are found to be insignificant for all models while quadratic effect of drum rotational speed is found effective for all

models.

When the variance analysis results of the weight yield are examined (Table 3), it is seen that the interaction between the magnetic field strength (A) and the feed rate (B) is statistically significant. This interaction is also shown in Fig. 3 as a three-dimensional graphic.

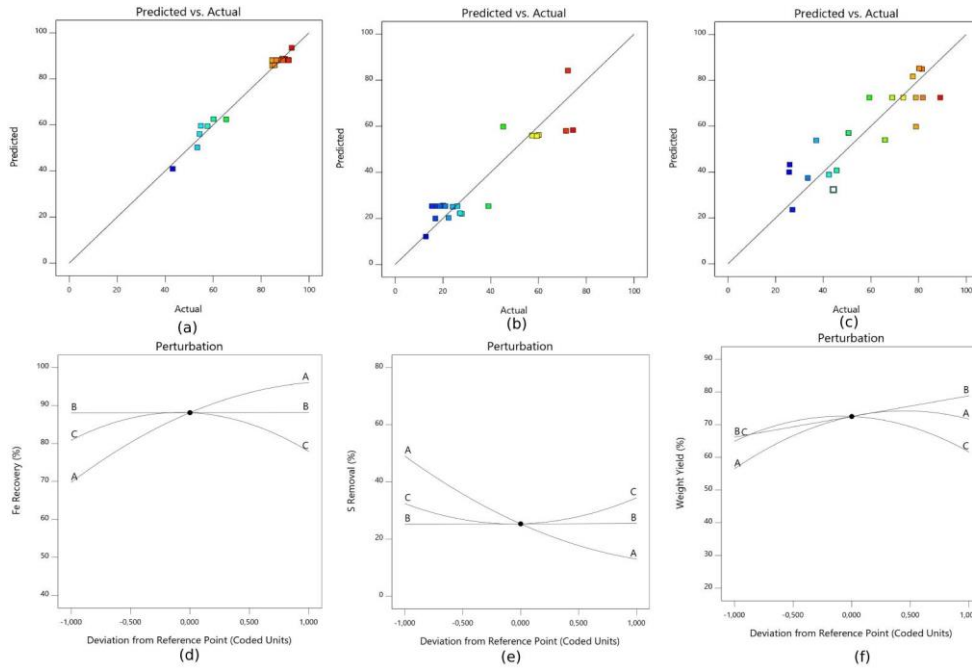


Figure 2. Graphical Representations of Analyses for DMS: Predicted Versus Actual (a:R_{Fe}; b:S_{Rem}; c:WY) and Main Effects of Parameters (d:R_{Fe}; e:S_{Rem}; f:WY)

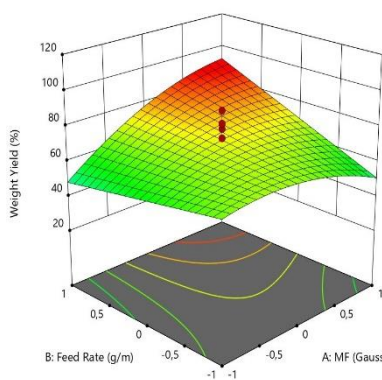


Figure 3. AB Interaction on WY for DMS.

As can be seen in Fig. 3, increasing the magnetic field strength caused a decrease in WY at low feed rate and an increase in high feed rate. This indicates that the effect of magnetic field intensity on the yield depends on the feed rate. This fact proves the interaction between

these two parameters.

4.2. Wet Magnetic Separation (WMS) Experiments

Table 3 shows the reduced ANOVA result for three response variables according to wet magnetic separation experimental results. Three regression models were created for iron recovery, sulphur removal rate and weight yield, and given in equations 7-9, respectively. Statistically insignificant terms were eliminated from the model with 95% confidence interval. Proposed models by software for all three response variables are significant as p values are less than 0.05. p values of Lack of fit for all models are greater than 0.05 which indicates experimental error is statistically insignificant.

$$RFe (\%) = 90.47 + 15.05 A + 0.86 B - 1.18 C - 6.67 A^2 \tag{7}$$

$$SRem (\%) = 23.75 - 18.54 A + 0.72 B - 0.49 C + 6.19 A^2 - 2.34 B^2 \tag{8}$$

$$WY (\%) = 78.33 + 20.96 A - 1.74 B + 1.45 C - 6.84 A^2 \tag{9}$$

R² values which represent the consistency of the models are obtained as 0.9162, 0.9476 and 0.8835 for R_{Fe}, S_{Rem}, and WY, respectively (Table 3). Graphical representation of predicted results versus actual results for all three response variables are given in Figs. 4 (a-c). As can be seen from the graphs, the R_{Fe}, S_{Rem}, and WY values estimated from the models represent the experimental results by approximately 92%, 95% and 88%, respectively which indicates the high consistency of all models. The fact that the correlation coefficients obtained for all response variables in wet magnetic separation are above 88% indicates that the uncontrollable noise factors are less effective in wet magnetic separation.

Table 3 also shows that P-R² values which represent the power of the models are obtained as 0.8043, 0.8863 and 0.7663 for R_{Fe}, S_{Rem} and WY, respectively. These values of P-R² indicate high power for all models

The main effects of parameters for R_{Fe} (%), S_{Rem} (%) and WY (%) are given in Figs. 4 (d-f), respectively. As it can be seen from the ANOVA Table (Table 3) and Figs. 4 (d-f), the most effective parameter for all response variables is the magnetic field strength (A). Both linear and quadratic effects of magnetic field strength are found to be significant for Iron recovery, sulphur removal rate and weight yield of the concentrate. Linear effects of feed rate (B) and solid ratio (C) are found to be insignificant for all models while quadratic effect of feed rate is found effective for sulphur removal.

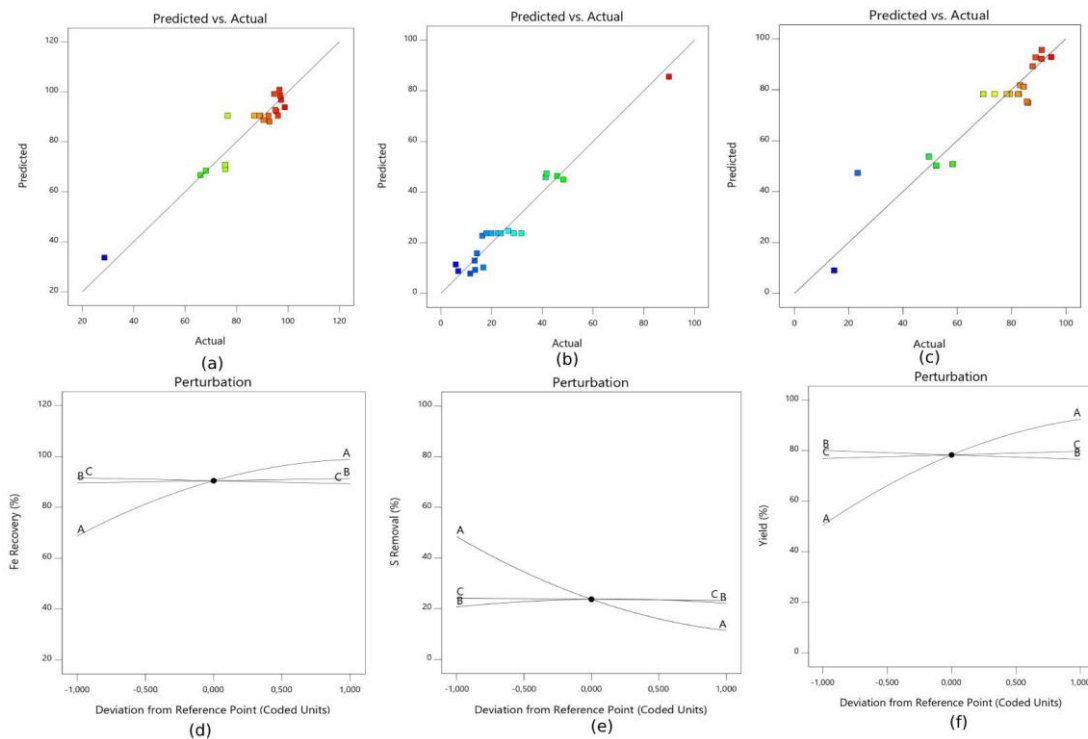


Figure 4. Graphical Representations of Analyzes for WMS: Predicted Versus Actual (a:R_{Fe}; b:S_{Rem}; c:WY) and Main Effects of Parameters (d:R_{Fe}; e:S_{Rem}; f:WY)

When the recovery of BOFs by magnetic separation are searched in the literature, studies performed by Alanyalı 2006, Menad 2014 and Lan 2017 have drawn attention.

In the first study, performed by Alanyalı 2006 by dry magnetic separator, was shown that the drum was the most effective parameter on the recovery of magnetic product. However, many data such as sulfur content, which have a significant effect on the recycling of iron, were not discussed in this study.

Menad 2014 has revealed the relationship between grinding type and grain size with both dry and wet magnetic separation efficiency in this study.

In the study presented by Lan 2017, the recovery of iron according to size fractions was studied by magnetic separation (wet or dry not mentioned) without no data on sulfur removal.

5. Conclusions

Recycling of iron and steel production plant wastes has been studied and the results of dry magnetic separation experiments showed that approximately one third of the wastes (33.47%) can be recycled with 54.90% iron recovery and 74.43% sulphur removal. This removal corresponds to 0.03% sulphur content, and the

concentrate can be blended back into the main raw material. The results of wet magnetic separation experiments showed that 14.66% of the wastes can be recycled with 28.60% iron recovery and 89.93% sulphur removal. This removal corresponds to 0.01% sulphur content, and the concentrate can be blended back into the main raw material.

The results obtained from two experimental sets, including dry and wet magnetic separation with the size of $-0.3 + 0.075$ mm, showed that the magnetic field strength should be increased to increase the iron recovery, but this negatively affected the sulphur removal rate. When trying to increase the sulphur removal rate, the iron recovery remains very low.

These removals correspond to 0.03% and 0.01% sulphur contents in the concentrates after dry and wet magnetic separations, respectively, and the concentrates can be blended back into the main raw material.

Finally, it has been shown that with a simple crushing-magnetic separation plant, the amount of wastes stored in the tailings dam and causing storage and environmental problems can be reduced.

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Contribution of Researchers

In this study; All three authors contributed equally to the planning of the studies, the realization of the experimental studies, and the interpretation of the results and the conversion of the results into reports.

Conflict of Interest

No conflict of interest has been declared by the authors.

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KAYNAK KISITLI ÇOKLU İNŞAAT PROJELERİNDE WIEST YÖNTEMİYLE İŞGÜCÜ KAYNAKLARININ TAHSİSİ VE DENGELMESİ ÜZERİNE BİR UYGULAMA

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Anahtar Kelimeler	Öz
<p><i>Kaynak Dengeleme Problemleri (KDP), Çoklu İnşaat Proje Yönetimi (ÇİPY), Kaynak Tahsis Modelleri (KTM), Kaynak Dengeleme Yöntemleri (KDY), Kaynak Kısıtlı Projelerde Dengeleme (KKPD)</i></p>	<p><i>Günümüzde inşaat projelerinin süre-maliyet açısından en iyi şekilde yönetilmesine ihtiyaç duyulmaktadır. Özellikle kısıtlı kaynaklar ile inşaat projelerinin yönetilmesi, uygulamada sıkça karşılaşılan bir problem olarak karşımıza çıkmaktadır. Buna ilave olarak, proje sayısı arttığında ve ortak kaynakların kullanılması durumunda, birçok iş programının birbirine geçtiği uygulamalarda, kaynakların projelere tahsisi, süre-maliyet açısından çok büyük önem arz etmektedir.</i></p> <p><i>Bu çalışmada kaynakları kısıtlı çoklu inşaat projelerinde; ortak işgücü kaynaklarının kullanılması durumunda, bu kısıtlı işgücü kaynaklarının projelerde nasıl kullanılacağı araştırılmıştır. Bu amaçla, WIEST kaynak dengeleme yöntemi kullanılarak işgücü kaynaklarının dengelenmesi ve tahsisi üzerine örnek bir uygulama yapılarak proje yönetimi ve iş programlarında yapılması gereken hususlar ele alınmıştır. Proje başlangıç tarihleri ve imalat metraj değerleri bilinen birbirinden uzak parsellerde inşa edilecek üç inşaat projesi ele alınmıştır. Bu projelerde ortak işgücü kaynaklarını kullanılması durumunda, bu işgücü kaynaklarının süre-maliyet açısından en uygun biçimde projelere entegre edilmesi amaçlanmıştır.</i></p> <p><i>Yapılan bu çalışmadan elde edilen bulgulara göre, aynı zamanda başlayacak ve işgücü kaynakları kısıtlı projelerde WIEST yöntemiyle işgücü kaynak dengelemenin kullanılması durumunda süre ve maliyet açısından birçok düzenlemenin yapılmasının gerekli olduğunu görülmüştür. Ayrıca proje sürelerinde belli bir artış olmasına rağmen proje maliyetlerinde azalma sağladığı görülmüştür.</i></p>

AN APPLICATION ON ALLOCATION AND BALANCING OF LABOR RESOURCES WITH WIEST METHOD IN RESOURCE LIMITED MULTIPLE CONSTRUCTION PROJECTS

Keywords	Abstract
<p><i>Resource Balancing Problems (RBP), Multiple Construction Project Management (MCPM), Resource Allocation Models (RAM), Resource Balancing Methods (RBM), Resource Limited Project Balancing (RLPB)</i></p>	<p><i>Nowadays, there is a need to manage construction projects in the best way in terms of time-cost. Managing construction projects, especially with limited resources, is a frequently encountered problem in practice. In addition, when the number of projects increases and common resources are used, the allocation of resources to projects is of great importance in terms of time-cost in applications where many construction schedules overlap.</i></p> <p><i>In this study, it has been investigated that how these limited resources can be used in projects in case of using common resources in multiple construction projects with limited resources. For this purpose, a sample application on the balancing and allocation of labour resources by using the "WIEST Resource Balancing Method" is conducted and the issues that need to be done in project management and construction schedules are discussed. Three construction projects to be built on distant sites with specific project start dates and manufacturing quantity values are considered. In case of using common labour resources in these projects, it is aimed to integrate these labour resources into the projects in the most appropriate way in terms of time-cost.</i></p> <p><i>According to the findings of this study, it shows that many adjustments in terms of time and cost are necessary in case of using labour resource balancing with the WIEST method in projects that will start at the same time and have limited labour resources. It has also been observed that although there is a certain increase in project durations, it provides a reduction in project costs.</i></p>



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* Sorumlu yazar: oyatekin@ogu.edu.tr<https://doi.org/10.31796/ogummf.1237568>**1. Giriş**

Proje yönetiminde en önemli husus kaynakların etkin kullanımı ve kısıtlı kaynaklar olması durumunda bu kaynakların en verimli şekilde iş planına uygun olarak koordine edilmesidir. Kaynakların bir iş planına bağlı olmadan gelişigüzel şekilde kullanılması, iş planında dalgalanmalara yol açar. Bu da yöneticiler için proje maliyetinin artmasıdır. Bu dalgalanmaların önlenmesi için uygulamada kaynakların doğru bir şekilde tahsis edilmesi ve dengelenmesi gerekmektedir. Tek bir inşaat projesinde dahi önemli olan kaynak yönetimi, aynı kaynakları kullanan çoklu inşaat projeleri için daha büyük önem arz etmektedir. Aynı zaman diliminde imalat süreci devam eden ve aynı kaynakların kullanıldığı inşaat projelerinde, kaynakların en verimli şekilde projelere tahsis edilmesi çok önemlidir. Bu gibi durumlarda kaynakların ortak kullanımı ve süre açısından en az kayıpla inşaat projelerinin devam etmesi istenir.

Son yıllarda özellikle inşaat projelerinde kullanılan işgücü ve makine kaynaklarının verimli kullanılması ve

düşük maliyetli projelerin gerçekleştirilmesinde kaynak tahsisi çok fazla önem kazanmıştır.

İnşaat proje yönetiminde, projelerin planlanması için kullanılan iş programlarından elde edilen kaynak kullanım çizelgelerinde dalgalanmalar oluşabilmektedir. Kaynaklarda oluşan bu dalgalanmalar, inşaat süresince çeşitli problemlere sebep olabilmektedir. Bu dalgalanmaları azaltmak için yapılan çalışmalar yapım için gerekli proje bütçesinin azaltılmasına da imkân sağlamaktadır. Bu sebeple KDP (Kaynak Dengeleme Problemleri) inşaat yönetiminde önemli bir problemdir. İnşaat sektöründe kullanılan KD yöntemleri üzerine yapılan çalışmalar incelendiğinde de sezgisel yöntemler ve üst sezgisel yöntemler adı altında gruplandırılacak çok sayıda yöntem ve uygulamaların olduğunu görebiliriz.

KDP, KTM (Kaynak Tahsis Modelleri ve ÇİPY (Çoklu İnşaat Proje Yönetimi) alanlarında yapılan çalışmalara ilişkin araştırma detayları Çizelge 1’de verilmiştir.

Çizelge 1. KDP (Kaynak Dengeleme Problemleri), KD (Kaynak Dengeleme) ve KTM (Kaynak Tahsis Modelleri) Alanında Yapılan Çalışmalar

Çalışma Alanı	Yapılan Çalışma	Kaynaklar
Kaynak Kısıtlı Projelerde Dengeleme (KKPD)	Sınırlı kaynaklara sahip büyük projeleri çizelgelemek için sezgisel bir model önerilmiştir.	Wiest (1967)
KD (Kaynak Dengeleme)	KD için kullanılan minimum moment yaklaşımına hesaplamaları önemli ölçüde düşüren bir değişiklik içeren algoritma önerilmiştir.	Hiyassat (2000)
KD (Kaynak Dengeleme), KTM (Kaynak Tahsis Modeli)	Faaliyetlerin uzamasına veya sıkıştırılmasına izin veren “entropi maksimizasyon metodu” adı verilen bir yöntem önerilmiştir.	Cristodoulou vd. (2010)
KD (Kaynak Dengeleme)	Klasik kaynak dengeleme problemi ve belirli bir kaynak kullanım eşiğinin aşılması durumunda maliyetlerin oluştuğu “aşırı yük problemi” olarak adlandırılan problemi çözmek için karma tam sayılı doğrusal programlama tekniği ile geliştirilen bir algoritma geliştirilmiştir.	Rieck vd. (2012)
KD (Kaynak Dengeleme)	Kaynak dengeleme problemlerinin çözümü için GA ağırlıklı bir algoritma önerilmiştir.	Iranagh ve Sönmez (2012)
KD (Kaynak Dengeleme), KTM (Kaynak Tahsis Modeli)	Bina inşaatları için bina bilgi modeli destekli kaynak dengelemesi gerçekleştirebilen bir uygulama geliştirilmiştir.	Yıldırım vd. (2016)
KDP (Kaynak Dengeleme Problemleri)	Belirsizlik altında kaynak kısıtlı çok modlu çoklu proje çizelgeleme	Soysal vd. (2021)
KDP (Kaynak Dengeleme Problemleri)	Proje süresini kısaltmak amaçlı, daha etkili ve esnek proje işlevleri için normalize entropi ve bağıl entropi değerlerine dayalı bir model önerilmiştir.	Qiao ve Li (2018)
Kaynak Kısıtlı Projelerde Dengeleme (KKPD)	Kaynak kısıtlı inşaat işlerinde iş gücü planlanması ve Kaynak Dengelenmesi için WIEST yönteminin bir uygulamasını içermektedir.	Erdoğan, O., 2021
KD (Kaynak Dengeleme)	KD için yeni paralel dal ve sınır algoritması önerilmektedir.	Ponz-Tienda vd. (2017)

Bu çalışmada kaynakları kısıtlı çoklu inşaat projelerinde ortak kaynakların kullanılması durumunda, bu kısıtlı kaynakların projelerde nasıl kullanılabilceği araştırılmıştır. İnşaat proje ve yönetimi alanında iş programlarının yapılmasında CPM ve PERT tabanlı yazılımlar sıkça kullanılmaktadır. Ancak CPM ve PERT tabanlı bu tür iş programları yapan yazılımlarda kaynakların kısıtlı olması durumu için bir iyileştirme yapma imkânı yoktur. Wiest yöntemi özellikle CPM tabanlı iş programları kullanılan projelerde; kaynakların tahsisi ve dengelenmesi amaçlı olarak yapılabilecek iyileştirmeler noktasında meta-sezgisel algoritmalar ve hibrit algoritmalar gibi diğer kaynak dengeleme yöntemlerine göre daha kolay uygulanabilmektedir. Bu amaçla, Wiest kaynak dengeleme yöntemi kullanılarak işgücü kaynaklarının dengelenmesi ve tahsisi üzerine örnek bir uygulama yapılarak proje yönetimi ve iş programlarında yapılması gereken hususlar ele alınmıştır. Daha önce yapılan çalışmalar incelendiğinde bu yöntemin tek ve bağımsız projelerde uygulandığını ama çoklu projelerde bu yöntem kullanılarak kaynak dengeleme veya kaynak tahsisi noktasında bir uygulama yapılmadığı görülmektedir. Bu amaçla Wiest yöntemi kullanılarak; proje başlangıç tarihi, imalat metraj değerleri bilinen 3 ayrı inşaat projesinin ortak işgücü kaynakları kullanılması durumunda bu işgücü kaynaklarının süre ve maliyet açısından en uygun biçimde projelere bütünleştirilmesi durumu araştırılmış, olumlu ve kabul edilebilecek bulgulara ulaşılmıştır.

2. Yöntem

Kaynakları kısıtlı çoklu inşaat projelerinde ortak kaynakların kullanılması durumunda, bu kısıtlı kaynakların kullanımının süre ve maliyet açısından projelerin yönetilmesinde ve uygulamada proje sürelerinin artması veya maliyetlerin yükselmesi gibi istenmeyen durumların ortaya çıkmasına neden olabilmektedir. İnşaat projelerinde sıkla karşılaşılan bu tip beklenmeyen ve istenmeyen durumların ortadan kaldırılması için çok sayıda sezgisel, istatistiksel ve matematiksel model ve yöntemlerin kullanıldığı bilinmektedir. Ancak bu zamana kadar yapılan çalışmaların bireysel ve sadece tek bir projede uygulandığı görülmektedir. Aynı tarihlerde ve farklı bölgesel şantiyelerde gerçekleştirilecek projelerin aynı yüklenim altında yapılması durumunda yüklenimi gerçekleştirecek olan yüklenicinin kaynaklarını bu çok sayıda ve aynı anda başlatılması gereken projelerde uygulanmasına yönelik yeterli olmayan az sayıda çalışmalara rastlanmaktadır. Özellikle kaynakları kısıtlı projelerde Wiest yönteminin uygulanmasında tek proje bazı çalışmalar yapılmıştır. Uygulamada kullanılacak olan Wiest yönteminin çoklu projelerde ne tür iyileşmeler veya sıkıntılar oluşturabileceği sorusuna cevap aramak amacıyla yapılan bu uygulamada projenin iş programlarının uygulanmasında Microsoft Project

yazılımından yararlanılarak oluşturulan CPM iş programları üzerinde KD yöntemlerinin özellikle Wiest Kaynak Dengeleme yönteminin uygulanabilirliği hedeflenmiştir.

2.1. Wiest Yöntemi

Wiest yöntemi, kaynak dengeleme problemlerini çözmeye yönelik pratik bir yaklaşım içeren ve özellikle CPM/PERT tabanlı iş planlaması yapılan projelerde kısıtlı kaynakların olması durumunda en uygun kaynak dengelemeye imkân sunan pratik bir yaklaşım önermektedir. Özellikle karmaşık bir projede yer alan hangi işlerin veya faaliyetlerin genel etkilerine göre daha yüksek öncelikli (veya kritik) olduğuna karar vermenin bir yolunu ortaya koyan bir yöntemdir. Ayrıca, zaman ve bütçe hedeflerini karşılamak için gereken tüm işler ve kaynaklar için ideal bir iş programı tasarlamaya yol ya da yollarını ortaya koyan bir yöntemdir.

J. D. Wiest tarafından geliştirilen (Wiest, 1967) ve daha sonra Azaron ve arkadaşları (Azaron A. vd., 2006) daha büyük, karmaşık ve uzun süreli inşaat projelerini analiz etmek, planlamak ve programlamak için kullanılan bu tekniğin geliştirilmesinde yer almışlardır.

Uygulamaya esas olan projelerde Wiest yöntemiyle kaynak dengeleme yapılırken sadece işgücü kaynağına göre dengeleme esas alınmıştır. Uygulama yapılırken Wiest yönteminin aşağıda sıralanan hususlara dikkat edilerek işgücü kaynak dengelemesi yapılmıştır:

- İlk olarak tüm aktivitelerin erken başlamaları hesaplanır ve her aktivitenin hangi gün ne kadar iş gücü gereksinimi duyduğu gösterilmelidir.
- Her işlemin en fazla gereksinim duyduğu iş gücü miktarı hesaplanmıştır.
- Projelere ait tüm aktivitelerin kaynaklarının en fazla olan bölgeleri bir birim aşağıya indirilmesi sağlanmıştır.
- Aktivite sıralaması sırasında işlem sırası göz önünde bulundurulmuş ve bunların tetikleme anında durdurulacağı öngörülmüştür.
- Bu işlem yapılarak sınırdaki veya sınırdan daha üstte bulunan aktiviteler belirlenmiştir.
- Sırası bozulmadan ve bitiş süreleri fazla uzamadan bu seviyenin üstündeki aktiviteler kaynak miktarları az olanlar üzere toplam bollukları ölçüsünde ötelemeler yapılmıştır.
- Diğer tüm aktivitelerin düzenlenmesi ve kaynak planlama grafiğine-tablosuna işlenmesiyle işlemler son işleme kadar devam edilmiştir.
- Eğer tekrar aşırı yüklenme yapılan aktiviteler varsa öteleme işlemine geri dönülmesi sağlanmıştır.

- Eğer tüm aktiviteler süresinde başarıyla tamamlanıyorsa tetikleme noktasını düşürmek için geri dönmüş ve işlem sürelerini ileriye ötelemeden vazgeçilmiştir.
- Eğer bu adımlarda başarısız olunursa en son yapılan düzenleme kabul edilerek işlemler tamamlanmış ve tetikleme seviyesinde eğer daha uygun bir durum yakalanamazsa son durum nihai sonuç kabul edilerek yeni iş programı ve zaman çizelgelemesi tamamlanmıştır.

Bu işlemler son işlem ötelemesine kadar her defasında tekrarlanır. Her denemede farklı sonuçlar elde edilmesi

kaçınılmazdır. Bu sebepten deneme sayısı artırılarak en uygun şartlar kabul seçilmelidir.

3. Uygulama

Çalışmada, uygulamaya esas olan projeler 3 adet olarak Eskişehir ilinde inşası düşünülen ve ruhsat aşamasında olan projelerden seçilmiştir. Birbirinden uzak parsellerde inşa edilecek bu projelerde kullanılması gerekli işgücü sayılarının belirlenebilmesi için bazı imalat miktarları proje üzerinden çıkarılmış, bazıları da piyasada sıklıkla kullanılan birim imalat miktarları ve adam/saat değerleri kullanılarak hesaplanmıştır (Kuruoğlu ve Bayoğlu, 2001). Projelere ait tahmini imalat miktarları Çizelge 2’de verilmiştir (Avdan, 2022).

Çizelge 2. Projelere ait Tahmini İmalatların Miktarları

İmalat Listesi	Birim İmalat Miktarları	Birim	Büyükdere Projesi	Şirintepe Projesi	Yenikent Projesi	Metraj Birimi
Betonarme Beton	0,38	m ³ /m ²	205.2	380,00	627,00	m ³
Betonarme Demiri	34,00	kg/m ²	18,36	34,20	56,10	ton
Kalıp	2,60	m ² /m ²	1404,00	2600,00	4290,00	m ²
Kalıp İskelesi	2,80	m ³ /m ²	1512,00	2800,00	4620,00	m ³
İş İskelesi	1,43	m ² /m ²	772.2	1430,00	2359.5	m ²
Tuğla Duvar	0,15	m ² /m ²	81,00	150,00	247.5	m ²
İç Sıva	2,40	m ² /m ²	1296,00	2400,00	3960,00	m ²
Dış Sıva	1,30	m ² /m ²	702,00	1300,00	2145,00	m ²
Tavan Sıvası	0,90	m ² /m ²	486,00	900,00	1485,00	m ²
Badana (İç)	3,00	m ² /m ²	1620,00	3000,00	4950,00	m ²
Fayans- Seramik	0,30	m ² /m ²	162,00	300,00	495,00	m ²
Ahşap Yapı + Karkas	0,15	m ² /m ²	81,00	150,00	247.5	m ²
Ahşap Pencere	0,12	m ² /m ²	64.8	120,00	198,00	m ²
Yağlı Boya	0,42	m ² /m ²	226.8	420,00	693,00	m ²
Mozaik Döşeme Kaplaması	0,90	m ² /m ²	486,00	900,00	1485,00	m ²

Yapımı üstlenen firmanın elindeki mevcut ve bu projede kullanacağı iş gücü kaynak miktarlarının kısıtlı olduğu kabul edilmiştir. İşgücü kaynaklarının kısıtlı olmadığı durum için oluşturulacak iş programları MS Project yazılımı kullanılarak yapılmıştır. Hesaplamalarda gün de 8 saat, haftada 6 gün çalışma yapılacağı kabul edilerek hesaplamalar yapılmıştır.

Kaynakların kısıtlılığı ile ilgili çalışma tamamen yüklenimi üstlenmiş olan firma öz kaynakları ve işgücü kaynaklarının durumuna göre belirlenmiş olup elde edilen İşgücü Kaynak Miktarları ortak iş gücü havuzu Çizelge 3’de gösterilmiştir.

Her imalatın toplam imalat süreleri bulunmuş ve bu süreler göre işgücü kaynakları kısıtlı olmadan iş programları oluşturulmuştur. Oluşturulan iş programların belli bir kısmı Çizelge 4’de verilmiştir.

İşgücü kaynaklarının kısıtlı olduğu durum dikkate alındığında; imalatların yapımında kullanılan işgücü kaynaklarına daha fazla ihtiyaç duyulacaktır. Fakat işgücü kaynaklarında kısıt kabul edildiğinde imalatlarda oluşan aşırı yüklemeye yapılmış (fazladan kaynak ihtiyacı doğmuş) ve aynı zaman dilimi içerisinde başlayan imalatlarda işgücü miktarlarında oluşacak çakışmalar karşımıza çıkacaktır. Aşağıda Şekil 1’de görüldüğü üzere proje başlangıç tarihlerinin aynı olması sebebiyle projelerdeki başlangıç faaliyetlerinde başta olmak üzere birçok imalatın yapımında kullanılacak olan ortak kaynak havuzu kullanılması sebebiyle kırmızıyla işaretlenmiş çakışmalar yaşanmaktadır.

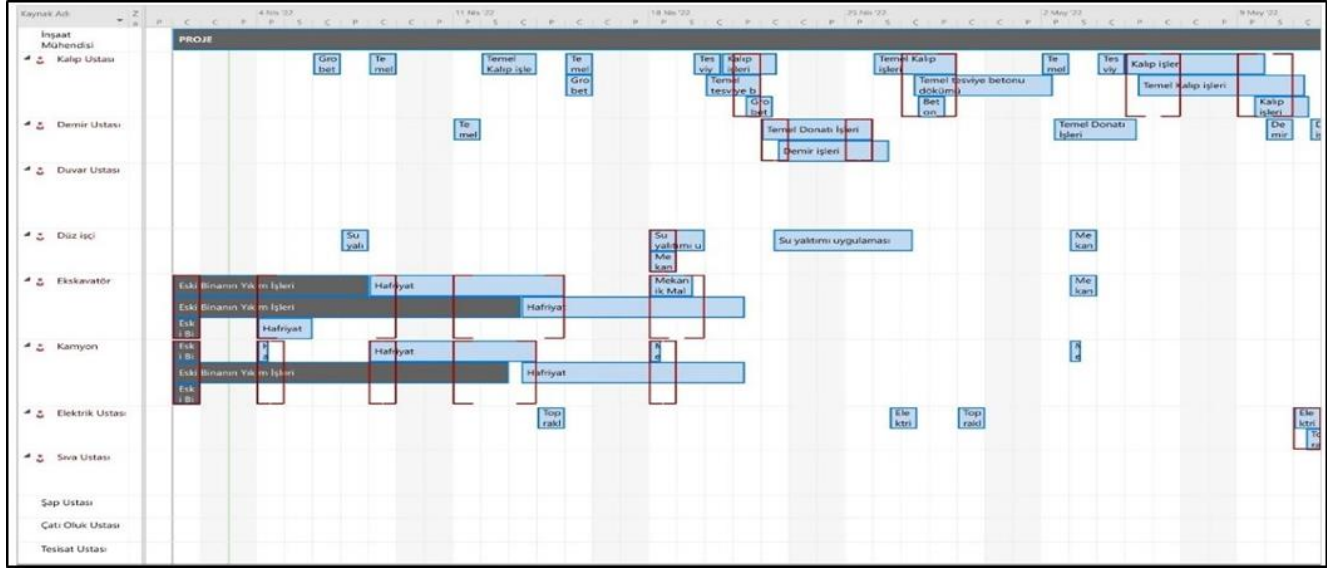
Çizelge 3. Üç Projede Kullanılacak İşgücü Kaynak Miktarları (Ortak İş gücü Havuzu)

Kaynak Adı	KAYNAK SINIRSIZ Adet	KAYNAK KISITLI Adet
Kalıp Ustası	5	3
Demir Ustası	9	3
Duvar Ustası	8	4
Düz işçi	6	1
Ekskavatör	3	1
Kamyon	6	2
Elektrik Ustası	5	2
Sıva Ustası	8	4
Şap Ustası	5	2
Çatı Oluk Ustası	3	2
Tesisat Ustası	4	2

Çizelge 4. Projeye Ait İşgücü Kaynak Kısıtlı Olmadan Yapılan İş programları

Görev Adı	Büyükdere Projesi			Şirintepe Projesi			Yenikent Projesi		
	Süre	Başlangıç	Bitiş	Süre	Başlangıç	Bitiş	Süre	Başlangıç	Bitiş
PROJE	79 gün	01.04.22	20.07.22	101 gün	01.04.22	19.08.22	149 gün	01.04.22	26.10.22
KABA İMALATLAR	73 gün	01.04.22	12.07.22	96 gün	01.04.22	12.08.22	149 gün	01.04.22	26.10.22
Temel	13 gün	01.04.22	19.04.22	24 gün	01.04.22	04.05.22	32 gün	01.04.22	16.05.22
Eski Binanın Yıkım İşleri	1 gün	01.04.22	01.04.22	5 gün	01.04.22	05.04.22	8 gün	01.04.22	08.04.22
Hafriyat	2 gün	04.04.22	05.04.22	5 gün	10.04.22	14.04.22	6 gün	15.04.22	20.04.22
Temel tesviye betonu dökümü	1 gün	08.04.22	08.04.22	2 gün	20.04.22	21.04.22	3 gün	27.04.22	29.04.22
Temel Yalıtımı	1 gün	01.04.22	01.04.22	2 gün	18.04.22	18.04.22	3 gün	24.04.22	26.04.22
Temel Donatı İşleri	3 gün	11.04.22	13.04.22	4 gün	22.04.22	25.04.22	5 gün	02.05.22	06.05.22
Temel Kalıp işleri	2 gün	12.04.22	13.04.22	3 gün	26.04.22	28.04.22	4 gün	05.05.22	10.05.22
Temel betonu	1 gün	15.04.22	15.04.22	1 gün	02.05.22	02.05.22	1 gün	12.05.22	12.05.22
Mekanik Malzeme Dolgu	1 gün	18.04.22	18.04.22	1 gün	03.05.22	03.05.22	1 gün	13.05.22	13.05.22
Bodrum Kat	23 gün	20.04.22	20.05.22	23 gün	05.05.22	06.06.22	31 gün	17.05.22	28.06.22
....
Zemin Kat	24 gün	09.05.22	09.06.22	30 gün	24.05.22	04.07.22	32 gün	08.06.22	21.07.22
1. Kat	24 gün	27.05.22	29.06.22	44 gün	14.06.22	12.08.22	32 gün	01.07.22	15.08.22
2. Kat	Bu projede 2. ve 3. kat yoktur.			15 gün	04.07.22	22.07.22	20 gün	26.07.22	22.08.22
3. Kat	Bu projede 2. ve 3. kat yoktur.			Bu projede 3. kat yoktur.			27 gün	18.08.22	23.09.22
Dubleks Mansart Katı	13 gün	16.06.22	04.07.22	8 gün	25.07.22	03.08.22	19 gün	06.09.22	30.09.22
Çatı	6 gün	05.07.22	12.07.22	8 gün	03.08.22	12.08.22	14 gün	03.10.22	20.10.22
İNCE İMALATLAR	12 gün	05.07.22	20.07.22	13 gün	03.08.22	19.08.22	18 gün	03.10.22	26.10.22

Açıklama: Kaba imalatlar ana iş gurubundan Temel imalatlar Grubunun detayları bu çizelgede ayrıntılı gösterilmiş olup diğer ana imalat gruplarının detayları gösterilmemiştir.



Şekil 1. Projelerde Oluşan İşgücü Kaynaklarında Aşırı Yükleme Oluşan Tarih ve İmalatların Bir Kısmı

Çizelge 5. WIEST Kaynak Dengeleme Yöntemi Uygulandıktan Sonraki İş programları

Görev Adı	Büyükdere Projesi			Şirintepe Projesi			Yenikent Projesi		
	Süre	Başlangıç	Bitiş	Süre	Başlangıç	Bitiş	Süre	Başlangıç	Bitiş
PROJE	101 gün	01.04.22	19.08.22	119 gün	04.04.22	15.09.22	180 gün	05.04.22	12.12.22
KABA İMALATLAR	96 gün	01.04.22	12.08.22	119 gün	04.04.22	15.09.22	174 gün	05.04.22	07.12.22
Temel	24 gün	01.04.22	04.05.22	36 gün	04.04.22	23.05.22	52 gün	05.04.22	15.06.22
Eski Binanın Yıkım İşleri	5 gün	01.04.22	05.04.22	6 gün	06.04.22	11.04.22	14 gün	12.04.22	23.04.22
Hafriyat	5 gün	08.04.22	13.04.22	9 gün	15.04.22	23.04.22	12 gün	16.04.22	28.04.22
Temel tesviye betonu dökümü	2 gün	08.04.22	09.04.22	3 gün	10.05.22	12.05.22	5 gün	13.05.22	17.05.22
Temel Yalıtımı	2 gün	18.04.22	19.04.22	2 gün	03.05.22	04.05.22	3 gün	13.05.22	15.05.22
Temel Donatı İşleri	1 gün	15.04.22	15.04.22	2 gün	11.05.22	12.05.22	3 gün	23.05.22	25.05.22
Temel Kalıp işleri	2 gün	18.04.22	19.04.22	3 gün	13.05.22	17.05.22	4 gün	03.06.22	08.06.22
Temel betonu	1 gün	02.05.22	02.05.22	1 gün	19.05.22	19.05.22	1 gün	10.06.22	10.06.22
Mekanik Malzeme Dolgu	1 gün	03.05.22	03.05.22	1 gün	20.05.22	20.05.22	1 gün	13.06.22	13.06.22
Bodrum Kat	23 gün	05.05.22	06.06.22	26 gün	26.05.22	30.06.22	62 gün	22.06.22	15.09.22
....
Zemin Kat	30 gün	24.05.22	04.07.22	34 gün	16.06.22	02.08.22	50 gün	15.07.22	22.09.22
1. Kat	44 gün	14.06.22	12.08.22	45 gün	8.07.22	8.09.22	37 gün	10.08.22	29.09.22
2. Kat	Bu projede 2. ve 3. kat yoktur.			15 gün	29.07.22	18.08.22	20 gün	09.09.22	06.10.22
3. Kat	Bu projede 2. ve 3. kat yoktur.			Bu projede 3. kat yoktur.			27 gün	04.10.22	9.11.22
Dubleks Mansart Katı	8 gün	25.07.22	03.08.22	20 gün	19.08.22	15.09.22	19 gün	21.10.22	16.11.22
Çatı	8 gün	03.08.22	12.08.22	8 gün	30.08.22	08.09.22	14 gün	17.11.22	06.12.22
İNCE İMALATLAR	13 gün	03.08.22	19.08.22	13 gün	30.08.22	15.09.22	18 gün	17.11.22	12.12.22

Açıklama: Kaba imalatlar ana iş gurubundan Temel imalatlar Grubunun detayları bu çizelgede ayrıntılı gösterilmiş olup diğer ana imalat gruplarının detayları gösterilmemiştir.

4. Bulgular

WIEST Kaynak Dengeleme Yöntemi kullanılarak ortak işgücü kaynak havuzunda mevcut olan kaynakların dengeleme yapılmadan ve yapıldıktan sonra oluşan işgücü kaynaklarına göre yapılan iş programlarına değişme olduğu gözlemlenmektedir. Bu durum proje sürelerinin artmasına neden olmuştur. Çizelge 4'de gösterilen dengeleme yapmadan önceki proje iş süreleri ile Çizelge 5'de gösterilen dengeleme yapıldıktan sonraki proje iş sürelerindeki değişim miktarları aşağıda Çizelge 6'de gösterilmiştir.

Çizelge 6. WIEST Kaynak Dengeleme Yöntemi Kullanılmasından Öncesindeki ve Sonrasındaki Proje Sürelerindeki Değişim

Proje Adı	Dengeleme Öncesi	Dengeleme Sonrası	Fark
Büyükdere Projesi	79 gün	101 gün	22 gün
Şirintepe Projesi	101 gün	119 gün	18 gün
Yenikent Projesi	149 gün	180 gün	31 gün

Proje sürelerinde oluşan değişimler dikkate alındığında oluşan ötelemeler sonunda 3 farklı proje için oluşturulan şantiyelerin bu süreler kadar daha aktif olarak çalışması gerektiği bunun da şantiye işletme giderlerinin artmasına yol açacağı görülmektedir. Şantiye işletme giderlerinde oluşan toplam proje maliyetlerine gelen fazladan maliyet yükleri piyasa şartlarına bağlı olarak hesaplandığında oluşan maliyet artışları Çizelge 7'de gösterilmiştir. Bu çizelgede hesaplanan değerlerin elde edilmesinde kullanılan günlük şantiye işletme giderleri yüklenimi üstlenen firmanın daha öndeki yapmış olduğu işlerden elde ettikleri değerler kullanılarak (Projelerin başlangıç ayı göre değil 2022 yılı Haziran ayına karşılık olarak) yaklaşık değerler olarak alınmış olup Çevre, Şehircilik ve İklim Değişikliği Bakanlığı İnşaat Birim Fiyatları kullanılmamıştır.

Çizelge 7. Şantiye Giderlerinde Oluşabilecek Maliyet Artışları

Proje Adı	Proje Süresindeki Artış	Günlük Şantiye Giderleri	Maliyet Artışları
Büyükdere Projesi	22 gün	450 TL/gün	9900 TL
Şirintepe Projesi	18 gün	600 TL/gün	10800 TL
Yenikent Projesi	31 gün	750 TL/gün	23250 TL

Proje sürelerinde artış olması sebebiyle şantiye genel giderlerinde artış olması uygulamada sanki maliyetleri artıran unsur olmasına rağmen kaynakların kısıtlı tutulmasından kaynaklı olduğunun unutulmaması gerekir. Hâlbuki kaynaklar kısıtlı olmadan yapılan planlamada daha fazla kaynak kullanılması durumu maliyeti artırdığını gözlemleyebiliriz. Kaynakların kısıtlı

olması durumunda atıl kaynak kullanmak yerine mevcut elde olan kaynakları kullanmanın avantajlı olduğunu WIEST Kaynak Dengeleme Yöntemi uygulandıktan sonra görebilmekteyiz. Çizelge 8'de kaynak kısıtlı olmadan ve kaynak kısıtlı olması durumunda yani WIEST Kaynak Dengeleme Yöntemi uygulamadan önceki ve sonraki durum için yapılan temel grubunu oluşturan imalatlarda ortaya çıkan maliyet azalışları gösterilmiştir.

Kaynakların kısıtlı tutulması ve bu kaynaklarla imalatların yapılabilme sürelerinin yeniden hesaplanmasıyla oluşturulan ve Çizelge 8'de gösterilen sonuçlara göre; temel grubu imalatları için dengeleme öncesi 465450 TL'lik işgücü ve şantiye genel gider maliyeti hesaplanmıştır. Bu şantiyeler arasında ortak işgücü kaynaklarının transferi için Eskişehir ili özelinde bir ek maliyet oluşturmadığı öngörülmüştür. Dengeleme sonrasında aynı grup imalatlarda 129700 TL'lik bir işgücü ve şantiye genel giderlerinde azalma olduğu hesaplanmıştır. Buna göre sadece temel grubu imalatlarında yaklaşık %27,88'lik bir maliyet azalması olduğu görülmektedir. Bu hesaplanan oranın sadece kaba inşaat kısmında olan maliyet azalmaları olduğuna dikkate edilmelidir. Tüm imalatlar noktasında bakıldığında bazı imatatlardaki işgücü maliyetlerin arttığı ancak genelde duruma göre ilk proje maliyetlerine göre önemli bir oranda maliyet azalması sağladığı görülmektedir.

4. Sonuçlar ve Öneriler

İnşaat sektörü maliyet ve süre bakış açısından en fazla proje yönetim unsurlarına önem verilmesi gereken bir sektördür. Özellikle kısıtlı kaynaklar ile gerçekleştirilecek olan projeler inşaat projeleridir. Üstelik proje sayısı arttığında ve ortak kaynakların kullanılması durumunda zaten karmaşık yapıda olan ve birçok iş ağının birbirine geçtiği inşaat sektöründe bu kaynakların projelere tahsisi, maliyet ve zaman açısından çok büyük önem arz etmektedir. Üstelik çok sayıda projenin aynı yüklenim altında ve aynı zamanda gerçekleştirilmesinde ortak kaynak havuzlarının kullanımını proje maliyetlerine ve sürelerine yapacağı olumsuz etkilerinin araştırılması ve yeni çözüm teknikleriyle proje yönetim unsurları oluşturulması gerekmektedir.

WIEST Kaynak Dengeleme yöntemi kullanılarak yapılan bu çalışmaya konu olan uygulamada elde edilen sonuçlar aşağıda sıralanmıştır:

- Kaynak kısıtlı olmayan projelerde kullanılan özellikle işgücü kaynaklarının kısıtlı olmadığı durumlarda şantiye genel giderlerinin daha da arttığı görülmektedir.

Çizelge 8. WIEST Kaynak Dengeleme Yöntemi Uygulamadan Önceki ve Uygulamadan Sonraki Bazı İmalatlarda Oluşan Maliyet Değişimleri

WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANMADAN ÖNCE (KAYNAK KISITI OLMADAN)									
İmalat	Toplam Süre	Kullanılan Kaynaklar	Kaynak Kullanım Günlük Giderler	Maliyet	Şantiye Günlük Giderleri	Şantiye Genel Giderleri	Toplam	Maliyet Azalması	
Hafriyat	Büyükdere 2 gün	3 Ekskavatör 6 Kamyon	1800 TL/gün (adet) 1300 TL/gün (adet)	70200 TL 101400 TL	Büyükdere 450 TL/gün	900 TL	180000 TL	48950 TL	
	Yenikent 5 gün				Şirintepe 600 TL/gün	3000 TL			
	Yenikent 6 gün				Yenikent 750 TL/gün	4500 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANDIKTAN SONRA (KAYNAK KISITLI)									
Hafriyat	Büyükdere 5 gün	1 Ekskavatör 2 Kamyon	1800 TL/gün (adet) 1300 TL/gün (adet)	46800 TL 67600 TL	Büyükdere 450 TL/gün	2250 TL	131050 TL		
	Yenikent 9 gün				Şirintepe 600 TL/gün	5400 TL			
	Yenikent 12 gün				Yenikent 750 TL/gün	9000 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANMADAN ÖNCE (KAYNAK KISITI OLMADAN)									
Yıkım İşleri	Büyükdere 1 gün	3 Ekskavatör 6 Kamyon	1800 TL/gün (adet) 1300 TL/gün (adet)	75600 TL 109200 TL	Büyükdere 450 TL/gün	450 TL	194250 TL		67900 TL
	Yenikent 5 gün				Şirintepe 600 TL/gün	3000 TL			
	Yenikent 8 gün				Yenikent 750 TL/gün	6000 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANDIKTAN SONRA (KAYNAK KISITLI)									
Yıkım İşleri	Büyükdere 5 gün	1 Ekskavatör 2 Kamyon	1800 TL/gün (adet) 1300 TL/gün (adet)	45000 TL 65000 TL	Büyükdere 450 TL/gün	2250 TL	125350 TL		
	Yenikent 6 gün				Şirintepe 600 TL/gün	3600 TL			
	Yenikent 14 gün				Yenikent 750 TL/gün	10500 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANMADAN ÖNCE (KAYNAK KISITI OLMADAN)									
Temel Grobeton	Büyükdere 1 gün	6 Kalıp Ustası	500 TL/gün	18000 TL	Büyükdere 450 TL/gün	450 TL	21900 TL	450 TL	
	Yenikent 2 gün				Şirintepe 600 TL/gün	1200 TL			
	Yenikent 3 gün				Yenikent 750 TL/gün	2250 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANDIKTAN SONRA (KAYNAK KISITLI)									
Temel Grobeton	Büyükdere 2 gün	3 Kalıp Ustası	500 TL/gün	15000 TL	Büyükdere 450 TL/gün	900 TL	21450 TL		
	Yenikent 3 gün				Şirintepe 600 TL/gün	1800 TL			
	Yenikent 5 gün				Yenikent 750 TL/gün	3750 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANMADAN ÖNCE (KAYNAK KISITI OLMADAN)									
Temel Yahtım	Büyükdere 1 gün	3 Düz İşçi	350 TL/gün	6300 TL	Büyükdere 450 TL/gün	450 TL	10200 TL		250 TL
	Yenikent 2 gün				Şirintepe 600 TL/gün	1200 TL			
	Yenikent 3 gün				Yenikent 750 TL/gün	2250 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANDIKTAN SONRA (KAYNAK KISITLI)									
Temel Yahtım	Büyükdere 2 gün	1 Düz işçi	350 TL/gün	3500 TL	Büyükdere 450 TL/gün	900 TL	9950 TL		
	Yenikent 3 gün				Şirintepe 600 TL/gün	1800 TL			
	Yenikent 5 gün				Yenikent 750 TL/gün	3750 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANMADAN ÖNCE (KAYNAK KISITI OLMADAN)									
Temel Kalıp	Büyükdere 2 gün	5 Kalıp Ustası	500 TL/gün	22500 TL	Büyükdere 450 TL/gün	900 TL	28200 TL	6750 TL	
	Yenikent 3 gün				Şirintepe 600 TL/gün	1800 TL			
	Yenikent 4 gün				Yenikent 750 TL/gün	3000 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANDIKTAN SONRA (KAYNAK KISITLI)									
Temel Kalıp	Büyükdere 2 gün	3 Kalıp Ustası	500 TL/gün	15000 TL	Büyükdere 450 TL/gün	900 TL	21450 TL		
	Yenikent 3 gün				Şirintepe 600 TL/gün	1800 TL			
	Yenikent 5 gün				Yenikent 750 TL/gün	3750 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANMADAN ÖNCE (KAYNAK KISITI OLMADAN)									
Temel Donatı	Büyükdere 1 gün	9 Demirci Ustası	500 TL/gün	27000 TL	Büyükdere 450 TL/gün	450 TL	30900 TL		5400 TL
	Yenikent 2 gün				Şirintepe 600 TL/gün	1200 TL			
	Yenikent 3 gün				Yenikent 750 TL/gün	2250 TL			
WIEST KAYNAK DENGELEME YÖNTEMİ UYGULANDIKTAN SONRA (KAYNAK KISITLI)									
Temel Donatı	Büyükdere 3 gün	3 Demirci Ustası	500 TL/gün	18000 TL	Büyükdere 450 TL/gün	1350 TL	25500 TL		
	Yenikent 4 gün				Şirintepe 600 TL/gün	2400 TL			
	Yenikent 5 gün				Yenikent 750 TL/gün	3750 TL			

- Kaynakların kısıtlı olmadığı durumlar için yapılan proje iş programlarında fazla kaynak kullanımının proje sürelerinin azalmasına imkân sağlamasına karşılık fazladan kaynak kullanımının maliyeti artırdığına işaret etmektedir. Tekli proje bazlı çalışmalarda yapılan uygulamalara bakıldığında süre ve maliyet açısından önemli faydalar elde edildiği bilinmektedir. Ancak çoklu projelerin aynı kaynaklarla ve aynı zamanlarda gerçekleştirilmesinde de bu faydaların elde edileceği konusunda yeterli çalışma olmadığını görmekteyiz.
- Buna karşılık kaynakların kısıtlı olması durumunda ise şantiye genel giderlerinde önemli derecede azalmalar sağlandığı görülmektedir.
- Uygulamada kullanılan kaynakları kısıtlı projelerde, WIEST Kaynak Dengeleme Yöntemi ile dengeleme yapıldığında; iş gücü maliyeti açısından fayda sağlasa da şantiye genel tamamlanma sürelerini arttırdığı görülmüştür. Sürelerin artmasına karşılık 3 proje için kullanılan kaynaklarının ortak olarak kullanılması ve kısıtlı olması halinde bile proje maliyetlerinde azalma sağladığı da görülmektedir.
- Bu çalışmadaki uygulamaya esas projeler benzer nitelikte konut tipi yapı projeleridir. Bu projelerin süre ve maliyet açısından küçük ölçekli projeler olması belki burada süre uzamasına karşın maliyetlerde azalma sağlamış olsa da, büyük projelerde bu durumun aynı olacağı söylenemez. Hatta konut tipi bina yapım projeleri dışında büyük ve kapsamlı birden çok projenin aynı anda ve aynı kaynakların kullanımıyla gerçekleştirilmesi durumunda da aynı faydaları vereceği konusu araştırılması gerekir. Çünkü büyük ölçekli projelerde oluşacak olan şantiye genel giderlerinin daha fazla olacağı, projelerin sürelerinin artması belki de proje maliyelerinin artabileceği durumu göz ardı edilmemelidir.
- Yapılan uygulamaya esas olan projelerin her ne kadar küçük ölçekli projeler olsa da kendi içlerinde kıyaslandığında küçük, orta ve büyük 3 proje olduğu dikkate alındığında, ilk başlangıç olarak küçük, orta ve büyük sıralaması dikkate alınarak projelerin ortak kaynak havuzu kullandıkları ve kaynakların kısıtlı çalışmada kullanılan projeleri kendi içlerinde büyük, orta ve küçük sıralaması dikkate alınarak bir kaynak dengeleme uygulaması yapılmamıştır. Eğer yapılmış olsa belki de daha faydalı bir çalışma karşımıza çıkabilir, daha olumlu sonuçlar alınabilmesi beklenmelidir.
- Çalışma sonucunda elde edilen bulgular ışığında WIEST Kaynak Dengeleme yöntemiyle daha uygun bir proje yönetimi gerçekleştirilebileceği görülmektedir.
- Özellikle çoklu inşaat projelerinde kaynakların kısıtlı olması ve ortak kaynak havuzu kullanılacak projelerde işgücü kaynaklarının daha verimli kullanılması noktasında önemli faydalar sağladığı görülmektedir.
- Özellikle proje sürelerinde artış olmasına rağmen şantiye genel giderlerinde artış olmasına rağmen proje imalatların büyük bir kısmında maliyet azalması sağladığı, proje genel maliyeleri noktasında özellikle işgücü kaynaklarının maliyetlerin azalma sağladığı,

daha verimli ve etkin bir şantiye iş programları oluşturulabileceği görülmektedir.

- Daha büyük ölçekli ve konut dışı projeler için özellikle çoklu projeler için aynı zaman diliminde ve aynı kaynakların kullanıldığı projelerde fayda sağlayabileceği konusunda yeni araştırmalar yapılmalıdır.

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EVALUATION OF DRINKING WATER TREATMENT PLANTS IN TERMS OF CAPACITY: THE CASE OF ISTANBUL, ANKARA, AND KOCAELI

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Keywords	Abstract
<p>Water resources Drinking water Population Urbanization Land Use</p>	<p>Global population growth is increasing the pressure on water resources day by day. At the same time, changes in land use, especially due to increased urbanization, affect hydrological processes. Considering both population and urbanization, the management of water resources with the right planning becomes inevitable. In this study, the worst-case scenario was handled and it was investigated how much more the city could meet its water needs if the drinking water treatment plants in the provinces of Istanbul, Ankara and Kocaeli were operating at full capacity. In the analyzes handled with the current water losses, the population projections and the future change in the per capita water need are revealed. According to the results obtained, it was determined that when the existing drinking water treatment plants in Istanbul are used at full capacity, there may be water shortages in 2039. Under the same conditions, it was determined that Ankara would not be able to meet its water needs in 2036. In Kocaeli, it was determined that in 2031, the existing facilities will be insufficient for the water demand. The results of the study showed that the necessary measures should be taken immediately for the water crisis, which is expected to be one of the most important problems of our country in the future.</p>

İÇME SUYU ARITMA TESİSLERİNİN KAPASİTE BAKIMINDAN DEĞERLENDİRİLMESİ: İSTANBUL, ANKARA VE KOCAELİ ÖRNEĞİ

Anahtar Kelimeler	Öz
<p>Su kaynakları İçme suyu Nüfus Şehirleşme Arazi Kullanımı</p>	<p>Küresel nüfus artışı, su kaynakları üzerindeki baskıyı her geçen gün artırmaktadır. Aynı zamanda özellikle de şehirleşmedeki artıştan dolayı arazi kullanımındaki değişiklikler hidrolojik süreçleri etkilemektedir. Hem nüfus hem de şehirleşme göz önüne alındığında su kaynaklarının doğru planlama ile yönetilmesi kaçınılmaz hale gelmektedir. Bu çalışmada en kötü senaryo ele alınarak İstanbul, Ankara ve Kocaeli illerindeki içme suyu arıtma tesislerinin tam kapasitede çalışması durumunda şehrin su ihtiyacını ne kadar daha sağlayabileceği araştırılmıştır. Mevcut su kayıpları ile ele alınan analizlerde nüfus projeksiyonları ile kişi başına su ihtiyacının gelecekteki değişimi ortaya konmuştur. Elde edilen sonuçlara göre İstanbul'daki mevcut içme suyu arıtma tesisleri tam kapasite ile kullanıldığında 2039 yılında su sıkıntısı yaşayabileceği belirlendi. Aynı koşullar altında Ankara'nın 2036 yılında su ihtiyacını karşılayamayacağı belirlendi. Kocaeli'de ise 2031 yılında mevcut tesislerin su talebine yetersiz kalacağı belirlendi. Çalışma sonuçları, gelecekte ülkemizin en önemli problemlerinden biri olması beklenen su krizi için gerekli önlemlerin ivedilikle alınması gerekliliğini göstermiştir.</p>

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1. Introduction

One of the most basic needs for human beings and other living beings to survive is water. Water covers approximately 71% of the earth's surface, with oceans accounting for approximately 96.5% of this water (USGS, 2019). In addition to playing an inevitable role in the ecosystem, water resources also play a critical role in the socioeconomic development of countries and regions (McGinn et al., 2021).

One of the main problems that mankind will face in the future will be getting access to water. With the increase in freshwater demand, freshwater scarcity poses a serious threat to the sustainable development of human society. Considering the potential effects of water scarcity, it appears to be one of the biggest global risks (Mekonnen & Hoekstra, 2016). Considering population growth, economic growth, and many different factors, it is seen that the pressure on water resources has increased. It is predicted that many parts of the world will face water scarcity due to factors such as global population growth and climate change (Moya-Fernández et al., 2021). In a study, it was determined that approximately 4 billion people experience water scarcity in at least one month of the year, and about half of these 4 billion people live in India and China (Mekonnen & Hoekstra, 2016).

In addition to the aforementioned factors such as climate change and population growth, changes in land use due to increasing urbanization, which contribute to climate change, have a significant impact on water resources by affecting the flow regime (Gashaw et al., 2018). Rapid urbanization causes problems such as insufficient water resources, a decrease in water quality, and environmental pollution (Qin et al., 2011). For these reasons, rapid urbanization is one of the biggest challenges to increasing water stress (Koç et al., 2020). Since the population is one of the most important factors in changes in land use due to urbanization, the relationship between urbanization and the population should be considered (Xu et al., 2020). For this reason, in this study, besides examining the changes in population and water demands, the relationship between urbanization and population will also be examined. In this study, population projections will be made by using the population data of Istanbul, Ankara, and Kocaeli provinces. The populations obtained will be analyzed together with the projections of the water consumption data, and it will be determined how sufficient the current drinking water treatment capacity of each province will be. At the same time, the relationship between urbanization and population will be revealed for the provinces mentioned. The results from the study will offer the planners a chance to get a general idea. Authorities will be able to benefit from this study in the planning and management of water resources as well as in the planning of drinking water treatment plants.

2. Material and Methods

2.1. Study Area

Istanbul, Turkey's most populous city and selected as the European Capital of Culture in 2010, Ankara, the capital of Turkey, and Kocaeli were chosen as the study areas. The locations of the study areas are given in Figure 1.

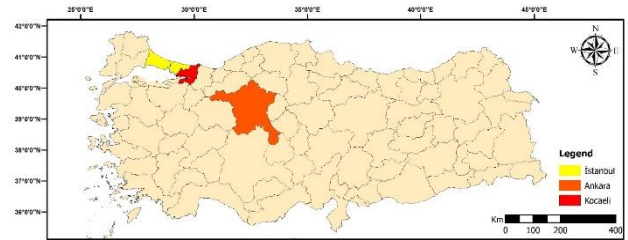


Figure 1. Locations of Study Areas

2.2. Data Collection

2.2.1. Population Data

Population data for the study areas were obtained from the Turkish Statistical Institute (TÜİK) data (TÜİK, 2022). Population data for the years 2000-2021 for Istanbul, Ankara, and Kocaeli, which are also used in the regression analysis, are given in Table 1.

Table 1. Population Data of Istanbul, Ankara, and Kocaeli

	Istanbul	Ankara	Kocaeli
2000	11,076,840	3,889,199	1,192,053
⋮	⋮	⋮	⋮
2015	14,657,434	5,270,575	1,780,055
2016	14,804,116	5,346,518	1,830,772
2017	15,029,231	5,445,026	1,883,270
2018	15,067,724	5,503,985	1,906,391
2019	15,519,267	5,639,076	1,953,035
2020	15,462,452	5,663,322	1,997,258
2021	15,840,900	5,747,325	2,033,441

2.2.2. Drinking and Utility Water Data

Data on drinking and utility water were obtained from annual reports published by each province's drinking and sewerage administrations. These institutions are the Istanbul Water and Sewerage Administration (İSKİ) for Istanbul, the Ankara Water and Sewerage Administration (ASKİ) for Ankara, and the Kocaeli Water and Sewerage Administration (İSU) for Kocaeli (İSKİ, 2022a; ASKİ, 2022a; İSU, 2022). While estimating the per capita water consumption in Istanbul and

Ankara in the coming years by using the current data, the equations in Figure 2 were used. Due to the sudden changes in the per capita water consumption data of Kocaeli, the regression analysis was not performed because the determination coefficient obtained was very small. Instead, the average per capita water consumption in Kocaeli in 2003–2020 is taken, and it is accepted that the average amount of consumption will continue in the coming years.

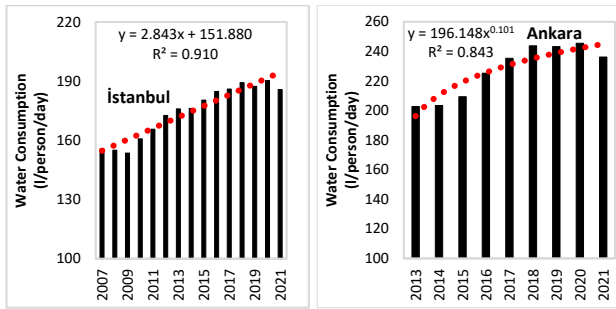


Figure 2. Per Capita Water Consumption in Istanbul and Ankara

2.2.3. Land Use Data

The land use data for the study areas were obtained from the Ministry of Agriculture and Forestry of the Republic of Türkiye (TCTOB, 2022). At the same time, satellite images of land use were obtained from the Copernicus Land Monitoring Service (CLMS), which is a part of the Copernicus Program (CLMS, 2022). Land cover maps by year are given in Figure 3.

2.3. Methods

In this study, per capita water consumption was calculated by dividing the total amount of water supplied to the cities annually by the total population of the cities. And with the regression analysis, population projections and water consumption projections for the study areas were obtained. The water loss rates obtained for the cities examined in the study show the total water loss. While considering the worst-case scenario, it has been calculated how long the cities can be sustained without facing a water shortage if the water treatment facilities already in place in the provinces under consideration are operating at full capacity. In order to analyze this situation, it is necessary to make a projection of the data for the coming years. For this reason, it is of great importance to analyze the data in the most accurate way statistically. Regression analysis is a statistical tool used to examine the relationship between two or more variables (Angelini, 2019).

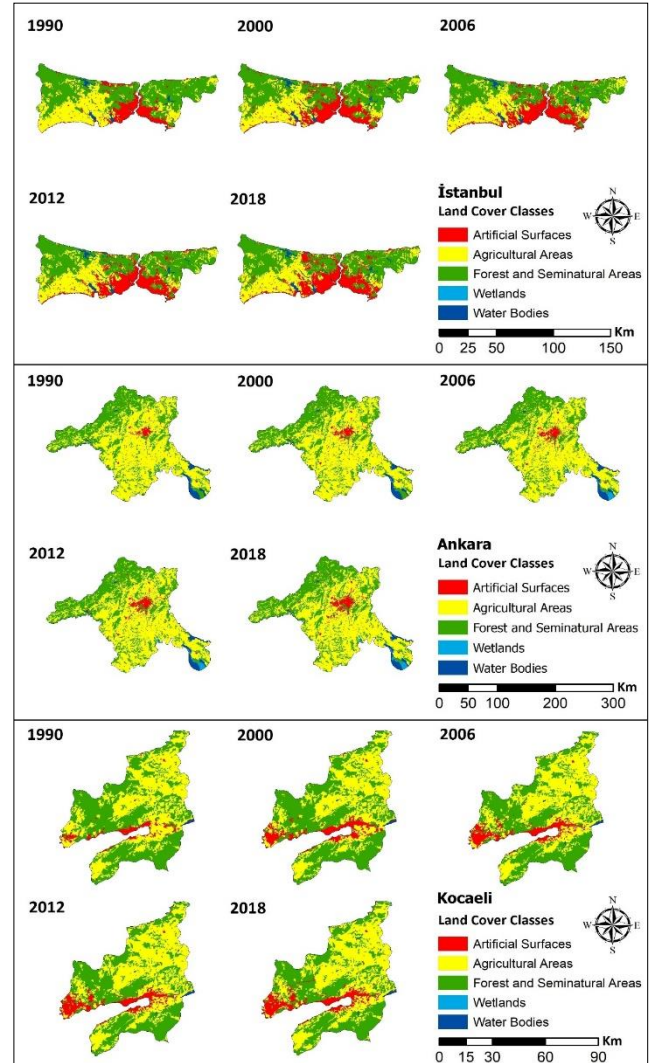


Figure 3. Land Cover Maps by Year

In this study, different regression models (simple linear, exponential and power) were used while performing the regression analysis. The reason for this is to achieve statistically more accurate results. The coefficient of determination (R^2), a concept belonging to regression analysis, is a measure of the rate of variance explained by the regression model (Di Bucchianico, 2008). Accordingly, in the study, the coefficients of determination of the relations between the variables were calculated for different regression models, and the regression model with the highest coefficient of determination was used. This process was applied separately in each study area when determining the water consumption and population projections. This method has also been used in different studies (Koç et al., 2017). At the same time, correlation analysis was carried out to reveal the relationship between population and urbanization in the study. In addition, the P-value was calculated by performing a hypothesis test to reveal the statistical significance of the data. The

path followed in the study is given schematically in Figure 4.

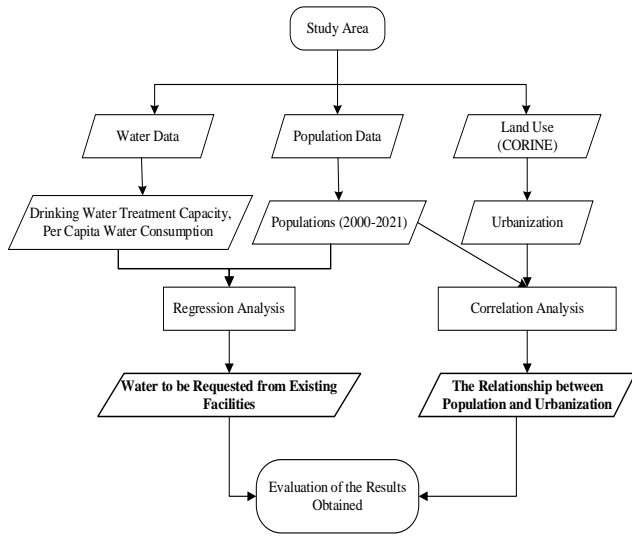


Figure 4. Flowchart of the Study

3. Results and Discussion

3.1. Results

3.1.1. Istanbul

As a result of the analysis carried out for the province of Istanbul, it has been concluded that even if the existing drinking water treatment plants in the province are operated at maximum capacity, there may be a water problem between 2038 and 2039. Figure 5 shows the amount of water per capita and water consumption per capita in Istanbul by year.

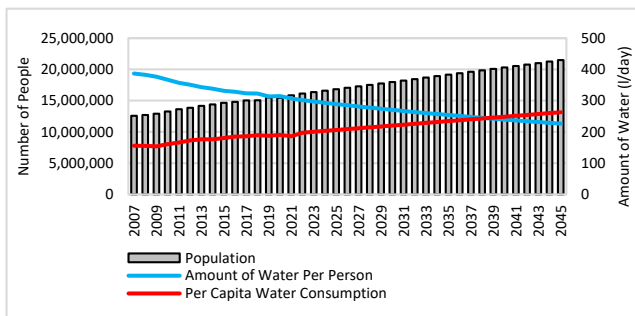


Figure 5. Amount of Water Per Capita and Per Capita Water Consumption in İstanbul by Years

When Figure 5 is examined, it is seen that the amount of water per capita decreased due to the increase in population. At the same time, the projection made depending on the amount of water consumed per capita

between 2007 and 2021 in Istanbul has an increasing trend.

Istanbul will have a population of approximately 20 million at the beginning of 2038. At the same time, the amount of water per capita for this year is 244.9 l/day. Per capita water consumption is expected to be 242.8 l/day in the aforementioned year. Hence, in 2038, a person's daily water needs can hardly be supplied. The amount of water demanded by a person during the year will become unaffordable by the existing facilities.

It is known that while the loss-leakage rate in Istanbul's drinking water network was 23.61% in 2017, it decreased to 20.52% in 2021 (İSKİ, 2022b). Unfortunately, if water losses continue at this level and the capacities of the existing treatment plants are not increased, a water shortage in Istanbul may occur in 2038. Efficient use of the city's water resources is of great importance with the efforts to reduce network losses. Drinking water network losses have been reduced below 10% in developed countries (TCOSB, 2017). If the network losses for Istanbul can be reduced to these levels, the current capacity will be sustainable until 2045.

In the simplest definition, urbanization is the process of increasing the number of people migrating from the countryside to the city, and it leads to the increase of artificial areas both vertically and horizontally (Hassan Rashid et al., 2018). The relationship between population and urbanization in Istanbul is given graphically in Figure 6.

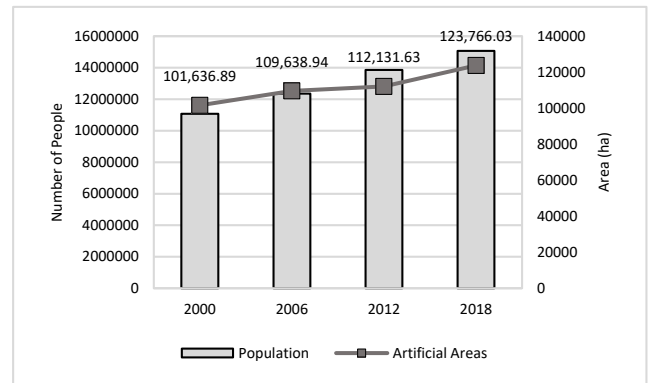


Figure 6. Population and Urbanization in Istanbul by Years

While Istanbul had an artificial area of 71,983.09 ha in 1990, this figure reached 101,636.89 ha in 2000. This shows an increase of approximately 41%. If we look more recently at Figure 6, in 2018, artificial areas cover 22.65% of Istanbul, with an area of 123,766.03 ha. This figure also constitutes the highest artificial area in the examined years.

A correlation analysis was performed using the data given in Figure 6. The correlation coefficient obtained to reveal the relationship between population and urbanization is 0.96. In order to reveal the statistical significance of the relationship, hypothesis testing was performed and the P-value was calculated (Asuero, et al., 2006). The P-value of the relationship was found to be $0.038 \leq 0.05$. This situation reveals that the relationship is statistically significant.

3.1.2. Ankara

As a result of the analysis, it has been determined that Ankara will not be able to meet its water needs in approximately 2035, even when the existing drinking water treatment plants in Ankara are operating at maximum capacity. Despite this, the year 2035, which is predicted to experience water shortages, is a very close date. Therefore, the number or capacity of drinking water treatment plants should be increased as soon as possible. In Figure 7, per capita water consumption and per capita water amounts are given in Ankara by year.

this rate is reduced to these levels, there will be no water shortage until 2063 with the current capacity.

In Figure 8, populations and artificial areas in Ankara are given by years.

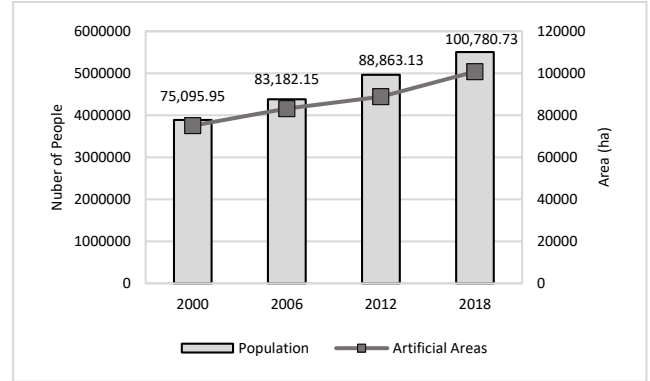


Figure 8. Population and Urbanization in Ankara by Years

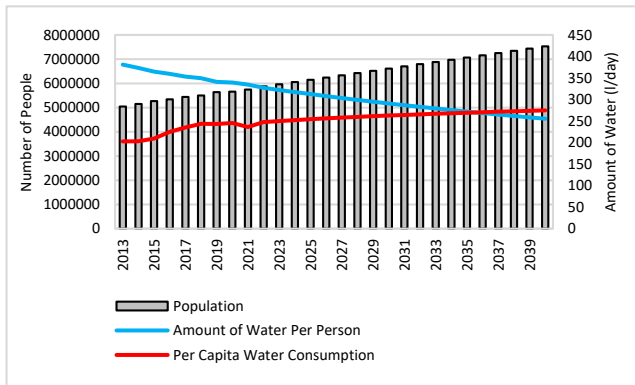


Figure 7. Amount of Water Per Capita and Per Capita Water Consumption in Ankara by Years

In Figure 7, per capita water consumption in 2021 is 236.14 l/day. The daily amount of water per person for the same year is 334.70 l. Therefore, the amount of water demanded per person in 2021 can be easily met. However, in Ankara, which is expected to have a population of more than 7 million in 2035, the per capita water consumption is 269.5 l/day, while the per capita water amount is 272 l/day. By 2036, the city's water needs will no longer be met. In the calculations made according to the reports of the Ankara water administration, the current water network losses are 37.25%. This rate is quite high. The relevant municipality is planning to reduce it to 30% in the first stage and then to 25% in target planning related to reducing losses. However, considering that this rate is around 10% in developed countries, it can be said that if

It can be seen in Figure 8 that urbanization (artificial areas) has increased continuously in Ankara. While the artificial zone area of Ankara was 55,045.59 ha in 1990, this area was 100,780.73 ha in 2018. This shows that urbanization has increased by more than 80% in 2018 compared to 1990. From 2012 to 2018 alone, urbanization in Ankara increased by about 13%.

A correlation analysis was performed using the data given in Figure 8. The correlation coefficient obtained to reveal the relationship between population and urbanization is 0.98. In order to reveal the statistical significance of the relationship, hypothesis testing was performed and the P-value was calculated. The P-value of the relationship was found to be $0.012 \leq 0.05$. This situation reveals that the relationship is statistically significant.

3.1.3. Kocaeli

The total capacity of the existing drinking water treatment plants in Kocaeli is 579,900.00 m³/day. It has been observed that even in the case of these facilities operating at full capacity, Kocaeli province may experience water shortages in the near future. In Kocaeli, which may experience water shortages shortly, the per capita water amounts and per capita water consumption by year are given in Figure 9.

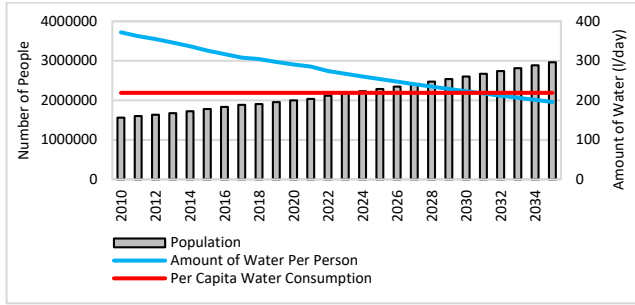


Figure 9. Amount of Water Per Capita and Per Capita Water Consumption in Kocaeli by Years

In Figure 9, per capita water consumption in Kocaeli has not changed over the years and is 219 l. This is because sudden changes in consumption data and a strong linear or exponential relationship between the data have not been determined. Therefore, a projection based on the regression analysis for water consumption was not performed. Instead, an average of 18 years of water consumption between 2003 and 2020 is taken. It is accepted that water consumption will be at the same level in the coming years. In 2021, while the water per capita in Kocaeli is approximately 285 l/day, the water consumption is 219 l. This means that the water demand per capita is met. However, it has been calculated that the amount of water per capita in 2030 will be 212.8 l/day. This figure is very close to the per capita water consumption value of 219 l/day. Therefore, the water demand in 2030 can hardly be met, but unfortunately, the amount of water demanded per person during the year will not be met. These calculations were made by taking into consideration the current network losses of Kocaeli (26%). Kocaeli water administration continues to work to prevent water losses and leaks. While network losses were 38% in 2016, it decreased to 26% in 2021. However, further reduction of this rate will make the existing drinking water capacity more sustainable. If water losses are reduced to 10%, the current drinking water capacity is expected to last until 2036.

Figure 10 displays statistics about Kocaeli's population and urbanization in a graphical format.

In Figure 10, artificial zone areas in Kocaeli were 14,107.64 ha in 1990, while this area reached 30,309.62 ha as of 2018. At the same time, the correlation coefficient obtained from Kocaeli's population and urbanization data is given in Table 5.

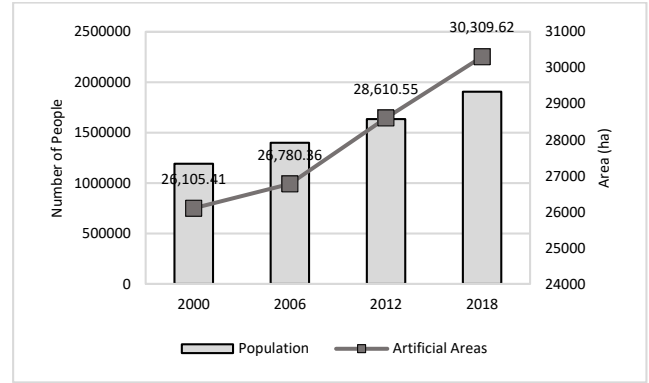


Figure 10. Population and Urbanization in Kocaeli by Years

A correlation analysis was performed using the data given in Figure 10. The correlation coefficient obtained to reveal the relationship between population and urbanization is 0.99. In order to reveal the statistical significance of the relationship, hypothesis testing was performed and the P-value was calculated. The P-value of the relationship was found to be $0.009 \leq 0.05$. This situation reveals that the relationship is statistically significant.

3.2. Discussion

In the report published by Kocaeli Water and Sewerage Administration (İSU), it is stated that the city will need 255,000,000 m³ of water in 2040 (İSU, 2021). In this study, the total water requirement in Kocaeli for the same year was calculated as 269,000,000 m³. In the drinking water and sewerage master plan report prepared for Istanbul, it has been calculated by the Cohort Component Technique that the population of Istanbul will be around 21 million in 2053. In this study, it was determined that Istanbul will have a population of 21 million in 2043. In the report published at the same time, it is predicted that per capita water consumption will be around 210 l/day in 2053. In this study, it is calculated that this figure will be reached in 2028 (İSKİ, 2022c). According to the report published for Ankara, population estimation was made according to three different scenarios to determine the population in the coming years. According to these scenarios, the population of Ankara in 2040 is expected to be between 7.8 million and 8.1 million. The population estimate for the same year in this study is approximately 7.6 million. According to the report, the per capita water consumption estimate for the metropolitan city for 2030, based on three different scenarios, varies between 188 l/day and 267 l/day. In this study, per capita water consumption for 2030 was estimated as 262 l/day. This figure is closer to the 267 l/day value obtained from the high consumption scenario in the report (ASKİ, 2022b). Therefore, the results obtained from the analysis in this

study are similar to the results in the published reports, especially in the reports published for Ankara and Kocaeli.

The method applied to determine water consumption and water demand in the coming years was used in a different study (Koç et al., 2017). However, in the study, network losses are taken into account in the analysis with their current values. However, municipalities continue to work on reducing network losses. In addition, it should not be forgotten that the years when water shortages are expected are for the worst-case scenario, since the case of drinking water treatment plants operating at full capacity is used in the analysis. Many studies have been carried out on both the determination and reduction of water losses (Ananda, 2019; Azevedo & Saurin, 2018; Saldarriaga & Salcedo, 2015). At the same time, researchers can achieve better results if they can determine the actual operating efficiency of drinking water facilities, which are assumed to operate theoretically with 100% efficiency in this study. In a study conducted in Chile, it was revealed that this rate varies depending on environmental factors, and only one of the facilities examined in the study has more than 81% efficiency (Molinos-Senante & Maziotis, 2022).

4. Conclusion

According to the results obtained in this study, it has been determined that drinking water treatment plants will not be able to meet the water needs of the population in Istanbul, Ankara, and Kocaeli in 2039, 2036, and 2031, respectively. Especially for Kocaeli, the results obtained from the study are quite worrying. Therefore, the authorities should speed up their current work on drinking water facilities in Kocaeli, taking this work into account. The status of the existing drinking water treatment plants in Istanbul and Ankara is better than in Kocaeli. However, in all cities in the study, planning should be done by taking into account the increasing population and urbanization. Otherwise, the water problem will become inevitable.

Water losses in these cities and in Turkey are quite high. According to an official report published, it has been revealed that the water loss rate in metropolitan municipalities in Turkey is approximately 50% (TCKB, 2018). While the water loss rate is more than 35% in Ankara in 2020 without including illegal uses, the total water loss in Kocaeli is 28% for the same year (ASKİ, 2021; İSU, 2021). In 2019, the only physical water losses in Istanbul are 20% (İSKİ, 2022b). In this context, the Ministry aims to create models that will provide technical and financial support in order to reduce water losses (TCKB, 2018). In a study conducted in 2019, it was suggested that the total water loss worldwide in 2006 was 346 million cubic meters per day (Liemberger & Wyatt, 2018). Considering the 6.5 billion world

population in 2006, the per capita water loss is around 50 l/day (PRB, 2006). This shows that water losses are a worldwide problem rather than a regional problem that only concerns Turkey. Therefore, reducing water losses is important for future generations to meet their water needs. In order to achieve this, it is necessary to increase the number of studies in this field and put them into practice by the authorities (Al-Washali et al., 2016; Al-Washali et al., 2020; Covas et al., 2008).

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Contribution of Researchers

Selami Yurdan Özgül contributed to the writing and analysis of the study. At the same time, this study emerged from S. Y. Özgül's master's thesis.

Yıldırım BAYAZIT contributed to the review of the study and the evaluation of the results.

Conflict of Interest

There is no conflict of interest.

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PARAMETER-LESS AND METAPHOR-LESS METAHEURISTIC ALGORITHM SUGGESTION FOR SOLVING COMBINATORIAL OPTIMIZATION PROBLEMS

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Keywords	Abstract
<p>Metaheuristic Algorithms Rao Algorithm Discrete Optimization Traveling Salesman Problem</p>	<p>Many optimization problems are complex, challenging and take a significant amount of computational effort to solve. These problems have gained the attention of researchers and they have developed lots of metaheuristic algorithms to use for solving these problems. Most of the developed metaheuristic algorithms are based on some metaphors. For this reason, these algorithms have algorithm-specific parameters to reflect the nature of the inspired metaphor. This violates the algorithm's simplicity and brings extra workload to execute the algorithm. However, the optimization problems can also be solved with simple, useful, metaphor-less and algorithm-specific parameter-less metaheuristic algorithms. So, it is the essential motivation behind this study. We present a novel metaheuristic algorithm called Discrete Rao Algorithm (DRA) by updating some components of the generic Rao algorithm to solve the combinatorial optimization problems. To evaluate the performance of the DRA, we perform experiments on Traveling Salesman Problem (TSP) which is the well-known combinatorial optimization problem. The experiments are performed on different sized benchmark problems in the literature. The computational results show that the developed algorithm has obtained high quality solutions in a reasonable computation time and it is competitive with other algorithms in the literature for solving the TSP.</p>

KOMBİNATORİYAL ENİYİLEME PROBLEMLERİNİN ÇÖZÜMÜ İÇİN PARAMETRESİZ VE METAFORSUZ METASEZGİSEL ALGORİTMA ÖNERİSİ

Anahtar Kelimeler	Öz
<p>Metasezgisel Algoritmalar Rao Algoritması Kesikli Eniyileme Gezgin Satıcı Problemi</p>	<p>Pek çok eniyileme problemi karmaşıktır ve çözülebilmesi için önemli miktarda hesaplama çabası gerektirmektedir. Söz konusu eniyileme problemleri araştırmacıların ilgisini çekmiş ve araştırmacılar bu problemlerin çözümünde kullanmak üzere birçok metasezgisel algoritma önermişlerdir. Geliştirilen metasezgisel algoritmaların çoğu metaforlara dayanmaktadır. Bu sebeple algoritmalar ilham alınan metaforların doğasını yansıtmak üzere parametre değerlerine sahiptirler. Bu durum algoritmanın sade olan yapısını bozmakta ve algoritmayı çalıştırmak için fazladan iş yükü getirmektedir. Ancak eniyileme problemleri sade, kullanışlı, metaforsuz ve parametresiz algoritmalarla da çözdürülebilir. Bu çalışmanın temel motivasyonu tam olarak söz konusu sade ve metaforsuz algoritma tasarımıdır. Bu çalışmada kombinatoriyal eniyileme problemlerini çözmek için yeni bir metasezgisel yöntem olan Kesikli Rao Algoritması geliştirilmiştir. Kesikli Rao Algoritması (KRA) bilinen Rao algoritmasının bazı bileşenlerinde güncellemeler yapılarak elde edilmiştir. KRA'nın performansı iyi bilinen bir kombinatoriyal eniyileme problemi olan Gezgin Satıcı Problemi (GSP) için değerlendirilmiştir. Literatürde yer alan farklı boyutlardaki test problemleri kullanılmıştır. Sonuç olarak, geliştirilen algoritma ile makul çözüm sürelerinde yüksek kaliteli çözümler elde edilmiştir ve geliştirilen algoritmanın GSP için literatürdeki diğer algoritmalarla yarışabilir nitelikte olduğu görülmüştür.</p>

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1. Introduction

Optimization is the process of determining the solution(s) that provide the best value for a given objective function(s). That's why, the problems, the optimal solution is tried to be obtained, are called optimization problems. These problems are encountered in several areas such as industry, engineering, science, finance etc. Optimization problems are basically divided into two classes as continuous and discrete with regard to the structure of decision variables (Papadimitriou and Steiglitz, 1998). In discrete optimization problems, decision variables take integer values, while decision variables are allowed to take continuous values in continuous optimization problems. In the combinatorial optimization problems which are in discrete optimization decision variables are required to belong to discrete set. This discrete set consists of objects belonging to the problem. So, combinatorial optimization problems can be defined as obtaining an optimal solution within a finite solution space (set of possible solutions) (Neos guide website, 2022). Some of the best known combinatorial optimization problems in the literature are knapsack problem, traveling salesman problem, vehicle routing problem and scheduling problem. According to the computational complexity theory, all combinatorial optimization problems are grouped under two classes, P and NP-hard. P class problems are easy and a polynomial time algorithm is available to obtain the optimal solution for this problems. For instance, shortest path, assignment and minimum spanning tree problems are belonging to P class. On the other hand, no polynomial time algorithm has not been discovered yet for any NP-hard class problems. For all of the problems in this class there exist exponential time algorithms. In other words, it will be very time consuming to solve larger instances of NP-hard problems with guaranteed optimality.

Many researchers have concentrated their research on combinatorial optimization problems. Thus, many methods and algorithms have presented to the literature in order to solve these problems. The methods used in the solution of these kind of problems are mainly divided into two classes: exact solution and approximate methods (Talbi, 2009). Exact solution methods guarantee obtaining the optimal solution. Dynamic programming, branch and bound algorithm, cutting plane method are the most frequently used exact solution methods.

Approximate methods can generate high quality solutions in a reasonable computation time and there is no guarantee of obtaining the optimal solution (Talbi, 2009). Heuristic algorithms, which are a member of the approximate methods, are categorized as problem-specific heuristic algorithms and metaheuristic

algorithms. Problem specific heuristics are tailored and designed to solve a specific problem. For instance, savings algorithm was proposed to solve the vehicle routing problem, while shifting bottleneck algorithm was developed to solve the job shop scheduling problem.

Metaheuristic algorithms are high-level strategies that guide problem-specific and local search methods to achieve high quality solutions in search space (Hussain, Mohd Salleh, Cheng, and Shi, 2018). These algorithms have various mechanisms to get out of local optima in the search space and are generally stochastic. The most important feature of metaheuristics is that they provide dynamic balance between two conflicting criteria: diversification and intensification. Diversification is exploration of the search space and it is aimed to reach the non-explored regions. Intensification is exploitation of the regions that provide high quality solutions more thoroughly.

Challenging problems have gained the attention of many researchers, and therefore, researchers have developed plenty of metaheuristic algorithms to obtain good solutions of these problems in reasonable time. Accordingly, there are many different metaheuristic algorithms in the literature. These proposed algorithms were detailed reviewed, explained and classified by Ezugwu et al. (2021), Singh and Kumar (2021), Agrawal, Abutarboush, Ganesh, and Mohamed (2021). The authors classified metaheuristic algorithms mainly as single solution based and population based. While the optimization process is performed using one solution in single solution based algorithms, a population of solutions is used in population based algorithms. In fact, almost all single solution based and population based metaheuristic algorithms are metaphor based. That is to say, researchers were inspired by some metaphors while developing these algorithms. These algorithms are sampled below.

Evolutionary based algorithms are inspired by natural evolution. Some of these are genetic algorithm (Holland, 1975), memetic algorithm (Moscato, 1989), genetic programming (Koza, 1992).

Swarm intelligence based algorithms are inspired by behavior of animals in mating, foraging, etc. Some of these are ant colony optimization (Dorigo, 1992), particle swarm optimization (Kennedy and Eberhart, 1995), artificial bee colony (Karaboga and Basturk, 2007), monkey search algorithm (Mucherino and Seref, 2007), cuckoo search (Yang and Deb, 2009), firefly algorithm (Yang, 2009).

Physics based algorithms are inspired by the rules of physics. Some of these are simulated annealing algorithm (Černý, 1985; Kirkpatrick, Gelatt Jr, and Vecchi, 1983), gravitational search algorithm (Rashedi, Nezamabadi-Pour, and Saryazdi, 2009), ray

optimization algorithm (Kaveh and Khayatazad, 2012), black hole algorithm (Hatamlou, 2013), water evaporation optimization algorithm (Kaveh and Bakhshpoori, 2016).

Human behavior based algorithms are inspired by social behavior of human. Some of these are group search optimizer (He, Wu, and Saunders, 2006), league championship algorithm (Kashan, 2009), teaching learning based optimization (Rao, Savsani, and Vakharia, 2011).

As far as we know, all these metaheuristic algorithms do not have obvious advantages over each other, although researchers claim that their algorithms are better. Because these algorithms are inspired by some metaphors, and they have algorithm-specific parameters. These parameters affect the performance of metaheuristic algorithm. Thus, it is necessary to determine the optimal values of the algorithm-specific parameters to get quality results. In this case, parameter tuning phase both increases the workload and may causes bias when comparing the algorithms.

Taking into account all of these, (Rao, 2020) shows a new metaheuristic algorithm, called as Rao Algorithm, with algorithm-specific parameter-less and metaphor-less. This algorithm is a population-based algorithm and has only two parameters to use in solving any problem. These parameters are population size and stopping criteria of the algorithm which are standard parameters for all population based metaheuristics. Rao algorithm was applied to constrained and unconstrained continuous optimization problems and it is stated that it performs well. Therefore, this algorithm has attracted the attention of researchers in a short time. Researchers have applied this algorithm to different fields such as design optimization of mechanical system components (Rao and Pawar, 2020a), optimal power flow problem (Gupta et al., 2021) and optimal design of dome structures (Dede, Atmaca, Grzywinski, and Rao, 2022). Moreover, different kinds of Rao algorithm have been developed such as evolutionary Rao algorithm (Suyanto, Wibowo, Al Faraby, Saadah, and Rismala, 2021), self-adaptive population Rao algorithm (Rao and Keesari, 2021), modified Rao algorithm (Pham and Tran, 2022), quasi-oppositional-based Rao algorithm (Rao and Pawar, 2020b), behavior selection Rao algorithm (Wei, Ouyang, Wu, Li, and Zou, 2022).

The purpose of this study is to develop a new version of the Rao algorithm to solve the discrete optimization problems. This novel Rao algorithm can be called as Discrete Rao Algorithm (DRA) and Traveling Salesman Problem (TSP) was used to show the performance of the developed algorithm. With this study, a metaphor-less and algorithm-specific parameter-less algorithm has been introduced to the literature to be used in any discrete optimization problems.

The following parts of the paper is structured as follows: Rao algorithm, DRA and TSP are explained in Section 2, computational results are presented in Section 3 and Section 4 consists of conclusion and future works.

2. Materials and Method

This study complies with scientific research and publication ethics and principles.

2.1 Rao Algorithm

Rao algorithm was introduced to the literature by Rao (2020). This algorithm is different from many population-based metaheuristic algorithms in the literature with regards to metaphor-less and algorithm-specific parameter-less. The main idea of this algorithm is to update the current solutions using the best and worst solution information in the population. In this way, neighbor solutions will be generated. This algorithm was originally developed for the solution of continuous optimization problems and the success of the algorithm was demonstrated on constrained and unconstrained continuous optimization problems. Its flowchart is demonstrated in Figure 1.

In the flowchart of the algorithm presented in Figure 1, the first point to note is that there are only two parameters to be determined. These are population size and stopping criterion of the algorithm. After these parameter values are determined, the initial solution for all candidates of the population is generated. Next, the neighbor solutions are generated for the candidates in the population. If the obtained neighbor solution is better than the current one based on the objective function value, it is accepted and the current solution is updated, otherwise it continues with the current solution. When the stopping criterion of the algorithm is met, the algorithm is stopped and the best solution in the population is reported.

Three different equations are used to generate neighbor solutions. These are presented below.

x_{ijk} : the value of the i^{th} variable for the j^{th} candidate during the k^{th} iteration.

x_{ilk} : the value of the i^{th} variable for the randomly selected candidate l during the k^{th} iteration.

x_{ibestk} , $x_{iworstk}$: the value of the i^{th} variable for the best or the worst candidate during the k^{th} iteration.

r_{1jk} , r_{2jk} : random numbers in the range $[0,1]$ for the i^{th} variable during the k^{th} iteration.

$$x'_{ijk} = x_{ijk} + r_{1ik}(x_{ibestk} - x_{iworstk}) \tag{1}$$

$$x'_{ijk} = x_{ijk} + r_{1ik}(x_{ibestk} - x_{iworstk}) + r_{2ik}(|x_{ijk} \text{ or } x_{ilk}| - |x_{ilk} \text{ or } x_{ijk}|) \tag{2}$$

$$x'_{ijk} = x_{ijk} + r_{1ik}(x_{ibestk} - |x_{iworstk}|) + r_{2ik}(|x_{ijk} \text{ or } x_{ilk}| - (x_{ilk} \text{ or } x_{ijk})) \tag{3}$$

Equation (1) generates a neighbor solution by sharing the information of the population's the best and the worst solutions to the current solution. On the other hand, with Equations (2) and (3), a neighbor solution is

generated by sharing information with the current solution from the best, the worst, and randomly selected solutions in the population. One of them is selected and used in the structure of the algorithm. The algorithm is named with regard to the equation to be used as the neighbor search operator. It is called Rao-1 algorithm if Equation 1 is used, Rao-2 algorithm if Equation 2 is used, and Rao-3 algorithm if Equation 3 is used in the structure of the algorithm. As explained, these algorithms are quite simple and can be easily adapted to solve any continuous optimization problems.

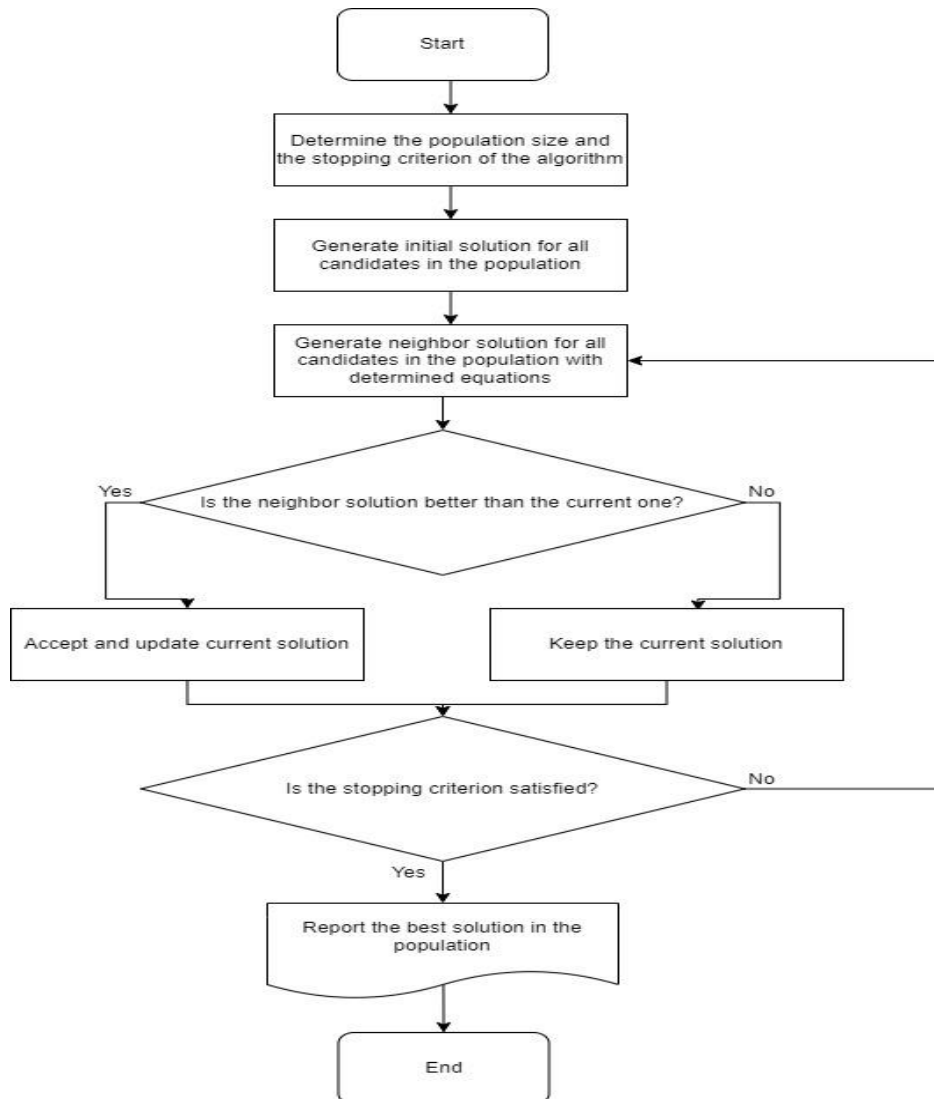


Figure 1. Flowchart of the Rao algorithm

2.2. Traveling Salesman Problem (TSP)

In the 1800s, William Rowan Hamilton created the groundwork for the TSP, which has been the subject of several research to this day. TSP is obtaining the shortest closed tour that allows a salesman to visit each

city in a given set just once. This problem is the most well-known combinatorial discrete optimization problem. TSP has various application areas such as drilling of printed circuit boards, overhauling gas turbine engines, x-ray crystallography, computer wiring, the order-picking problem in warehouses and vehicle routing etc. (Matai, Singh, and Mittal, 2010). In

addition, it is the most notable Np-hard problem (Laporte, 1992). That is to say, algorithms that can solve the related problems in polynomial time are not known yet. As the size of the problem increases, the computation time also increases exponentially. Researchers can get detailed information regarding the types of TSP and solution approaches for these problems from Gutin and Punnen (2006) and Applegate, Bixby, Chvátal, and Cook (2011).

Mathematical model of TSP is given below.

Indices:

$i, j = \{0, 1, \dots, N\}$ nodes (cities)

Parameter:

c_{ij} : distance value between $i - j$

Decision Variables:

$x_{ij} = \begin{cases} 1, & \text{If salesman goes from } i \text{ to } j \\ 0, & \text{otherwise} \end{cases}$

$u_i = \text{sub - tour elimination variables}$

Model:

$$\min Z = \sum_i \sum_j c_{ij} x_{ij} \quad (4)$$

$$\sum_i x_{ij} = 1 \quad \forall j \quad (5)$$

$$\sum_j x_{ij} = 1 \quad \forall i \quad (6)$$

$$u_i - u_j + nx_{ij} \leq n - 1 \quad \forall i, j \quad i \neq j, i \geq 2, j \geq 2 \quad (7)$$

$$x_{ij} \in \{0, 1\}, u_i: \text{free} \quad (8)$$

Equation (4) is the objective function minimizing the total travelled distance. Equations (5) and (6) guarantee that each node (city) is just visited once. Equation (7) prevents the sub-tours that proposed by Miller, Tucker, and Zemlin (1960). Equation (8) shows the sign constraints.

As the size of the problem increases, the time required to solve the problem increases exponentially. So, this problem belongs to the NP-hard class. For this reason, researchers have proposed heuristic and metaheuristic algorithm to solve it in a reasonable computation time. Accordingly, we proposed a novel DRA to solve this problem efficiently manner.

2.3. Discrete Rao Algorithm (DRA)

The generic Rao algorithm is developed for solving continuous optimization problems. So, some changes are needed in the structure of the algorithm in order to use it in solving combinatorial optimization problems. Since the generic Rao algorithm is algorithm-specific

parameter-less, it will be sufficient to modify the neighbor search process. The equations used as the generating neighbor solution in the generic structure of the algorithm are suitable for the continuous optimization problems. Thus, we propose new neighbor search operators to the algorithm. These operators work well for permutation solution representation used for combinatorial optimization problems.

Four different neighbor search operators have been proposed for DRA. These are detailed below.

Two-Point Crossover: This operator will be applied to a randomly selected candidate for each iteration. The information carried by the best or the worst solution in the population will be transferred to the selected candidate. Crossover points are randomly determined for the selected candidate. The part between the determined crossover points is preserved. The other parts of the candidate are updated based on the order of the best or the worst candidate. Please note that up to half of the randomly selected candidate's information should be updated by the best or the worst solution.

Insert Operator: A randomly selected position value in the current solution is inserted to the another randomly generated position. This operator is applied only for the best solution in the population. Thus, the algorithm will continue to focus more on quality solution areas.

Swap Operator: The values of two randomly selected position are exchanged. This operator supports to the intensification mechanism of the algorithm like insert operator. So, it is also applied only for the best solution in the population.

Reverse Operator: For other candidates in the population (except for the randomly selected candidates), the neighbor solution is generated by the reverse operator. With this operator, two different position points are randomly generated in the current solution and the values between these points are reversed. Therefore, it can make major changes to the current solution. Thus, it prevents the algorithm from getting stuck into the local best points.

By using the proposed operators, neighbor solutions are generated for all candidates in the population in each iteration. In other words, they are operated in accordance with the basis of the generic Rao algorithm. The flowchart of the DRA is shown in Figure 2.

Figure 2 indicates schematically the process of the DRA. When the DRA flowchart is analyzed, it is clear that it reflects the spirit of generic Rao algorithm. Because it is algorithm-specific parameter-less and the information from the best solution in the population is employed during the generating neighbor solutions.

Moreover, the proposed algorithm has insert, swap, reverse and two-point crossover operators that will provide intensification and diversification. Thus, the dynamic balance between diversification and intensification mechanisms of the algorithm will be provided. One of the three operators (swap, insert, reverse) is randomly selected to obtain a neighbor solution from the best solution in the population. For a randomly selected solution, the neighbor solution is

generated by applying two-point crossover method using either the best or the worst solution. For other candidates of the population, the neighbor solution is obtained using the reverse operator. By this way, all current solutions in the population are updated and new neighbor solutions are generated in each iteration of the proposed algorithm. At the end, we can say that the algorithm is ready for use in solving combinatorial optimization problems with these components.



Figure 2. Flowchart of the DRA

3. Computational Results and Discussion

The developed DRA algorithm is applied to solve the TSP. The components of the algorithm are designed as follows.

Solution representation: Permutation solution representation is implemented in accordance with the TSP. An example of solution representation for TSP with 7 cities is shown in Figure 3.

3	7	5	1	4	6	2
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Figure 3. Solution Representation of TSP

Evaluating the solution representation shown in Figure 3, the vehicle route is obtained as Depot – City 3 – City 7 – City 5 – City 1 – City 4 – City 6 – City 2 – Depot. So, the length of this solution representation depends on the number of cities.

Neighbor search operators: Neighbor search operators in the structure of the proposed algorithm are appropriate for permutation solution representation. Figure 4 summarizes the working mechanisms of the neighbor search operators used in the structure of the proposed algorithm.

Swap Operator							
Current Solution	3	7	5	1	4	6	2
Suppose two randomly selected positions are 4 and 6.							
Neighbor Solution	3	7	5	6	4	1	2
Insert Operator							
Current Solution	3	7	5	1	4	6	2
Suppose two randomly selected positions are 1 and 4.							
Neighbor Solution	7	5	1	3	4	6	2
Reverse Operator							
Current Solution	3	7	5	1	4	6	2
Suppose two randomly selected positions are 2 and 5.							
Neighbor Solution	3	4	1	5	7	6	2
Two Point Crossover							
The Best Solution	6	3	2	4	5	7	1
Current Solution	3	7	5	1	4	6	2
Suppose two randomly selected positions are 2 and 4.							
Neighbor Solution	6	7	5	1	3	2	4

Figure 4. The Working Mechanism of the Neighbor Search Operators

As can be seen from Figure 4, neighbor search operators will be used as described in the previous title.

Stopping criterion: The number of iterations is used as the stopping criterion of the proposed algorithm.

The performance of the algorithm has been tested on different sized test problems taken from the literature (TSPLIB website). The information about these problems and the determined values of population size and number of iterations, which are the two parameters of the algorithm used in the solution of these problems, are shown in Table 1.

Table 1. Parameter Values of the DRA

Test Problem	Number of Nodes	Population Size	Number of Iteration
GR17	17	10	1000
GR24	24	10	1000
SWISS42	42	10	10000
GR48	48	10	10000
EIL51	51	10	25000
ST70	70	10	40000
EIL76	76	10	45000
KROA100	100	10	50000
EIL101	101	10	50000
KROA150	150	10	75000
XQG237	237	50	35000
PBL395	395	50	50000
XQL662	662	50	75000

In Table 1, the names of the test problems, the number of nodes (cities) in the test problems, the number of candidates to be included in the population and the number of iterations are presented from the left column to the right respectively. For instance, KROA100 problem contains 100 nodes, and the parameter values of the algorithm specified as (population size, number of iterations) = (10, 50000). As can be seen in Table 1, as the size of the problem increases, the number of iterations required to solve the problem has also increased. This is because as the size of the problem increases, it becomes more difficult to solve. Moreover, for large scale problems such as XQG237, PBL395 and XQL662 the population size is set to 50 in order to prevent the algorithm from getting stuck into the local best points. In addition, the mechanism of generating neighbor solution for these problems is the same as in Figure 2 for the best and randomly selected candidates, while it is different from the structure in Figure 2 for other candidates in the population. The neighbor solution for these candidates

is obtained as follows; half of the candidates to be selected randomly are replaced with the best solution and then reverse operator is applied to these candidates. Thereby, it is intended that the algorithm can be able to better explore for quality solution regions.

The suggested method was coded in Python 3.7 and executed on an Intel Core i5 personal computer at 1.8 GHz with 8 GB of RAM. It has been run 10 times for each test problem and the gap value have been presented in Table 2. The gap value was calculated as presented in Equation (9).

$f(s)$ = The obtained objective function value with DRA.

$f(s^*)$ = The optimal objective function value.

$$\text{Gap} = (f(s) - f(s^*)) / f(s^*) \quad (9)$$

Table 2. Computational Results of the DRA

Test Problem	The Optimal Results	The Obtained Results	Gap	Computation Times (second)
GR17	2085	2085	-	0.272
GR24	1272	1272	-	0.363
SWISS42	1273	1273	-	5.965
GR48	5046	5046	-	6.434
EIL51	426	426	-	17.587
ST70	675	679	0.006	36.256
EIL76	538	546	0.016	46.935
KROA100	21282	21343	0.003	67.163
EIL101	629	638	0.015	68.454
KROA150	26524	27349	0.031	159.061
XQG237	1019	1074	0.054	950.607
PBL395	1281	1392	0.087	1509.308
XQL662	2513	2794	0.112	4602.709

The computational results of the test problems obtained by the DRA are given in Table 2. In this table, column 2 indicates the gap value between the DRA algorithm's solution and the optimal solution, column 3 shows the computation time of the algorithm in seconds. Researchers can find the optimal solutions of these problems from the TSPLIB website.

The optimal solution of the problems up to the 51 nodes was obtained by the DRA at a reasonable computation time (less than 17 seconds). For the problems with the number of nodes between 70 and 662, solutions can be obtained with acceptable deviations from the optimal solution. Besides, the quality solutions can be obtained in a short computation time even for the large scale problems. For the XQL662 test problem, which is the most challenging one, quality solution could be obtained in approximately 4602 seconds (1 hour 20 minutes) with a deviation of about %11 from the optimal solution. For the KROA150 test problem, high quality solution could

be obtained in approximately 159 seconds with a deviation of about 3% from the optimal solution. Namely, the obtained results are promising and the performance of the DRA is high for the TSP. It can be interpreted that the proposed DRA is effective to solve the TSP. In order to demonstrate the convergence capability of the proposed algorithm, the convergence graph of the DRA for KROA150 is indicated in Figure 5.

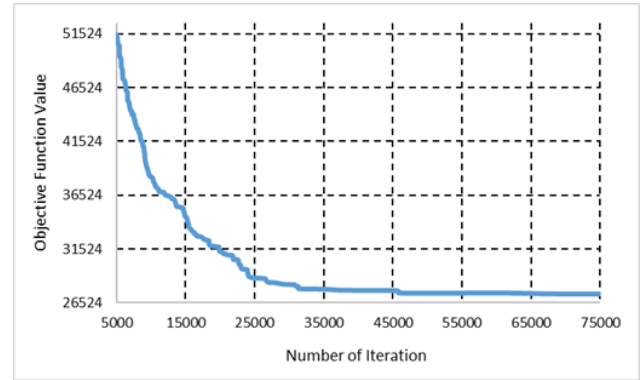


Figure 5. Convergence graph of the DRA

The objective function values on the y axis and the number of iterations on the x axis are represented in the graph. Since the optimal objective function value (total traveled distance) of the KROA150 problem is 26524, the convergence pattern of the DRA is presented to this value. In order to properly display the algorithm's convergence graph, the section after the 5000th iteration of the algorithm is described, and the obtained objective function values in this section are exhibited. The convergence speed of the algorithm is quite high, especially in the first 33% of the total number of iterations. In other words, the algorithm quickly reaches quality solutions. Then, it is clearly seen that the convergence speed of the algorithm decreases gradually as the number of iterations increases. The reason for this is that the algorithm reaches quality solution regions and tries to ensure intensification in these regions. So, the developed algorithm gets the high quality solutions.

4. Conclusion

In this study, a critical approach has been brought to the metaheuristic algorithms used in solving difficult problems in the literature. Such that most of the metaheuristic algorithms in the literature are inspired by some metaphors and have algorithm-specific parameters. Therefore, the use of these algorithms imposes an extra burden on researchers since it is necessary to determine the values of algorithm-specific parameters. Furthermore, as far as we know, the superiority of these algorithms over one another has not been proven yet. This has been the inspiration and starting point for the research. So, Rao algorithm,

metaphor-less and algorithm-specific parameter-less metaheuristic method, has been discussed. Originally, this algorithm was developed to solve the continuous optimization problems. In this paper, we present a novel metaheuristic algorithm called as DRA by updating some components of the generic Rao algorithm to solve the combinatorial optimization problems. The performance of the developed algorithm has been shown on TSP test instances. The obtained results are promising and the developed algorithm has obtained high quality solutions in a reasonable computation time.

The developed algorithm has provided that high quality solutions are obtained. However, since the information of the best and worst solutions is used in the generating neighbor solution stage, the population may contain similar solutions. In this case, similar solutions in the current population may need to be updated. In addition, the proposed algorithm only accepts solutions that improve the current solution. But, it may be possible to benefit from the knowledge of solutions that do not improve the existing solution by using the probabilistic acceptance criterion. So, both the diversity in the population is ensured and it becomes possible to prevent the algorithm from getting stuck into the local best points.

In summary, this study shows that researchers do not have to use the metaphor based metaheuristic algorithms to solve the combinatorial optimization problems. Because, it has been proven that the combinatorial optimization problems can also be solved easily with simple, useful, metaphor-less algorithm. This is a potential area for further research.

It may be useful to develop different versions of the DRA and execute it to solve different combinatorial optimization problems in future works.

Author's Contributions

The authors confirm contribution to the paper as follows: study conception and design: Aydın SİPAHİOĞLU; computational experiments: İslam ALTIN; analysis and interpretation of results: İslam ALTIN and Aydın SİPAHİOĞLU. All authors reviewed the results and approved the final version of the manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

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